DYNAMO LABORATORY OUTLINES

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FOR STUDENTS IN
ELECTRICAL ENGINEERING

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PREFACE

The preparation of these Outlines was undertaken with the idea of supplying a laboratory manual of limited scope and cost yet containing such material as would meet the requirements of electrical engineering courses generally. To this end a study was made of all available information regarding the laboratory work of a large number of American universities and technical schools. It was found impracticable to include, in this volume, every experiment listed by these schools but the substance of every experiment having general engineering interest has, the writer believes, been incorporated.

While the writer does not believe in "spoon feeding" neither can he subscribe to the other extreme of making the student an independent discoverer of the facts and principles pertaining to the laboratory assignment. The tourist, visiting Colorado, saves time and gains more information by employing a competent guide than by starting out alone to "discover" Pike's Peak. The tourist, however, gains little information by simply following the guide. He must use his faculties of observation. So the laboratory student may be lead, by means of a proper outline, to certain experimental facts which he should connect with the theory as developed in the class-room or by outside reading.

These Outlines, therefore, consist of short but explicit instructions regarding the performance of the experiment, and conclude with a list of questions covering both the theory and the practical operation of the appar studied. (It is not expected that the questions a will cover all phases of the subject that may arise instructors may find it advantageous to ask additional questions.)

It is not intended that the order in which experiments are arranged in this volume should indicate the order in which they should be performed. Neither is it expected that the subject-matter under one heading should, necessarily, be covered in one laboratory period. The subdivisions of the subjects make it possible to omit parts of any subject where, for lack of time or any other reason, it may be deemed advisable.

The results of the use of these Outlines in the writer's classes at the University of Michigan have been most satisfactory but corrections or suggestions for their improvement will be gladly received from any one interested.

The thanks of the writer are due Prof. Benj. F. Bailey, of the University of Michigan, for encouragement in the preparation of these Outlines and for suggestions for their improvement; also to Mr. Walter M. Rennie and to Mr. G. W. Snedecor for reading and correcting the manuscript.

J. F. W.

THE UNIVERSITY OF MICHIGAN,
January, 1913.

CONTENTS

GENERAL INSTRUCTIONS

Protection of Apparatus

Any electrical apparatus that is to be used in experimental work should be connected to the supply circuit by means of a double-pole switch and protected from excessive currents by suitable fuses or circuit breakers. Time and trouble will be saved if all connections are carefully checked before closing the switch. During the early part of the experiment it is well to keep a sharp lookout for trouble, particularly for overheated coils, rheostats and bearings.

Instruments

Select instruments of such a range and scale division that accurate readings may be obtained. Ammeters are to be connected in series with the load, voltmeters in shunt (parallel) with the load. A wattmeter is a combination of ammeter and voltmeter coils acting on one moving element. Wattmeter diagrams and connections will be found at the end of this volume.

Data

All observations must be accurately and neatly tabulated. Sample calculations should be included in the written report so that both the method and the metical result may be readily checked.

CURVES

Curves should be drawn in ink on cross-section paper. Draw smooth curves through as many of the experimental points as possible. It is not expected that a curve (which is simply a method of averaging results) will pass through every experimental point determined. Both the looks and the value of a curve depend much on the selection of the scales to which the curve is to be drawn.

QUESTIONS

At the end of each experiment will be found a list of questions. Each of these is to be answered briefly but explicitly.

REFERENCES

No attempt has been made to explain the theory involved in the experiment. The student is expected to look this up for himself. The more thoroughly he does this, the greater will be the benefit derived from the work. As an aid to this end, a few selected references are added at the end of each experiment. Other references may readily be found in any good engineering library and the student is urged to form the habit of looking up the views of different writers on any subject under consideration.

ACCIDENTS

The treatment for electric shock is so simple and failure of its immediate application so fatal, that a lack of knowledge of the treatment, particularly among electrical men, is little short of criminal.

The immediate effect, when the body comes in contact with an electric conductor of any considerable voltage, is a suspension of the act of respiration. Artificial respiration must be established immediately or death is inevitable. The fact that immediate action must be taken if the life of the patient is to be saved cannot be too strongly impressed. Life or death is a question of a very few seconds but only after the heart ceases to act is the case hopeless and of this a qualified physician is the only person competent to judge.

RULES RECOMMENDED BY

Commission on Resuscitation from Electric Shock

REPRESENTING

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The National Electric Light Association
The American Institute of Electrical Engineers

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Electrician, General Electric Company

MR. W. D. WEAVER, *Secretary*
Editor, Electrical World

Follow these instructions even if victim appears dead.

I. IMMEDIATELY BREAK THE CIRCUIT

With a single quick motion, free the victim from the current. Use any *dry non-conductor* (clothing) rope, board, to move either the victim or the wire. Beware of using metal or any moist material. While freeing the victim from the live conductor have every effort also made to shut off the current quickly.

II. INSTANTLY ATTEND TO THE VICTIM'S BREATHING

1. As soon as the victim is clear of the conductor, rapidly feel with your finger in his mouth and throat and remove any foreign body (tobacco, false teeth, etc.). Then *begin artificial respiration at once.* Do not stop to loosen the victim's clothing now; *every moment of delay is serious.* Proceed as follows:

(*a*) Lay the subject on his belly, with his arms extended as straight forward as possible and with face to one side, so that nose and mouth are free for breathing (see Fig. 1). Let an assistant draw forward the subject's tongue.

FIG. 1.—Inspiration; pressure off.

(*b*) Kneel straddling the subject's thighs, and facing his head; rest the palms of your hands on the loins (on the muscles of the small of the back), with fingers spread over the lowest ribs, as in Fig. 1.

(*c*) With arms held straight, swing forward slowly so that the weight of your body is gradually, but *not violently*, brought to bear upon the subject (see Fig. 2). This act should take from two to three seconds.

(*d*) Then immediately swing backward so as to remove the pressure, thus returning to the position shown in Fig. 1.

(*e*) Repeat deliberately twelve to [illegible] times a minute the swinging forward and back—a co[illegible]tion in four or five seconds.

(*f*) As soon as this artificial res[illegible] started, and while it is being continued, an assistant should loosen any tight clothing about the subject's neck, chest, or waist.

2. Continue the artificial respiration (if necessary, two hours or longer), *without interruption*, until natural breathing is restored, or until a physician arrives. If natural breathing stops after being restored, use artificial respiration again.

FIG. 2.—Expiration; pressure on.

3. *Do not give any liquid by mouth until the subject is fully conscious.*

Give the subject fresh air, but keep him warm.

III. SEND FOR NEAREST DOCTOR AS SOON AS ACCIDENT IS DISCOVERED

DIRECT CURRENTS

1

Preliminary Study

The object of this experiment is to study the structural details of the different types of dynamo and the construction and operation of motor-starting rheostats.

1. Study the electrical and the mechanical construction of the following types of dynamo:

(*a*) shunt.
(*b*) series.
(*c*) compound.

2. Draw a diagram of the electrical circuits of each of the machines studied.

3. Make a sketch for each machine studied showing each of the following parts in its relation to the others, explain its function, its construction and state of what material it is made:

(*a*) armature core.
(*b*) field core.
(*c*) yoke.
(*d*) commutator.
(*e*) brushes.

4. Draw a diagram of the electrical circuits of a motor-starting rheostat having "no-load" "over-load" releases and indicate how it is c o the circuit of a shunt motor.

[illegible] ammeter [illegible]

[illegible] ammeter

[illegible] with

[illegible] maximum

[illegible]

[illegible] sheets [illegible] instead of being made in one solid [illegible]

[illegible] necessary that the field cores [illegible] laminated?

[illegible] and [illegible] compound dynamo.

[illegible] using a motor-starting rheostat.

[illegible] release and how [illegible]

[illegible] "over-load" release and how [illegible]

[illegible] mechanism is often used in place of the [illegible] release.

[illegible] difference between a "motor" and a "generator."

(*i*) by means of diagrams, the determination of the resistance of the armature winding and of the field winding.

REFERENCES

Franklin & Esty, Direct Currents, Chap. 2 and pp. 112–116.
Karapetoff, Exp. Elec. Eng., Chap. 15–16.
Smith, Testing Dynamos & Motors, pp. 81, 95, 110.

2

THE SHUNT GENERATOR

The object of this experiment is to study the shunt dynamo as a generator.

1. Building Up.—(*a*) Connect a shunt dynamo as in Fig. 1, drive it at constant speed and measure the voltage

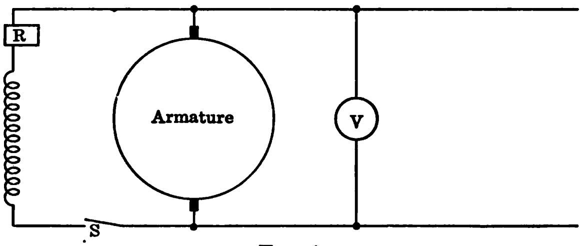


FIG. 1.

(1) with the field circuit open.
(2) with the field circuit closed.
(3) with the field terminals reversed.

(*b*) Drive the dynamo at the same speed, but in the opposite direction, and repeat (*a*).

(*c*) Explain

(1) how a voltage is generated when circuit is open.

(2) why, with a given field connection, a shunt generator will build up when rotated in one direction but will not build up when rotated in the other direction.
(3) why, with a given direction of rotation, a shunt generator will build up when the field current flows in one direction but will not build up when the field current flows in the opposite direction.

2. Characteristics.—(*a*) Connect as in Fig. 2, drive at the rated speed with such excitation as will give rated voltage at full-load and determine the following for current outputs up to 150 per cent. of the rated load:

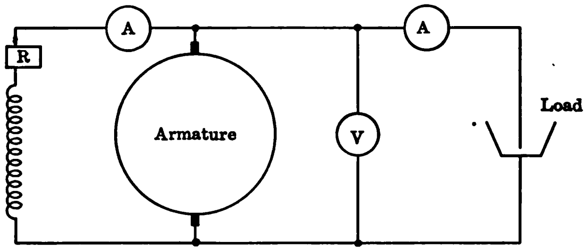


FIG. 2.

(1) field amperes.
(2) terminal voltage.

(*b*) Determine the armature resistance.

(*c*) Define
(1) total characteristic.
(2) external characteristic.
(3) regulation.

(*d*) Using current as abscissa and e.m.f. as ordinates, plot
(1) the external characteristic.
(2) the internal characteristic.

(3) the armature drop.
(4) the field current.

(*e*) Calculate the voltage regulation.

(*f*) Explain, by means of a diagram, the determination of the armature resistance.

3. Components of Voltage Drop.—As the load on a shunt generator increases the voltage decreases (speed and field resistance remaining constant). This voltage drop is due to

(1) the resistance of the armature circuit.
(2) armature reaction.
(3) decreased field current.

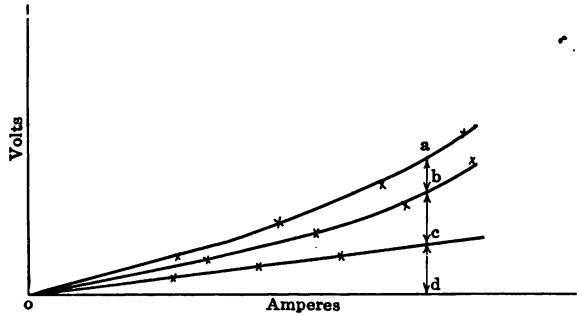


FIG. 3.

(*a*) From the data taken for the characteristic (or from the curve itself) determine the voltage drop for different values of armature current and plot as *oa* in Fig. 3.

(*b*) Keeping the field current constant (separate excitation), determine the voltage drop for several values of armature current and *ob*.

(*c*) Calculate the resistance drop and plot

Then, for the armature current, *od*, *ab* is the drop due to the decreased field current, *bc* is that due to armature reaction and *cd* is that due to the resistance of the armature circuit.

(*d*) Explain
(1) how the resistance drop varies.
(2) armature reaction.
(3) why the field current decreases as the load increases.

4. Armature Characteristic.—The armature characteristic shows the relation between field excitation and armature current, the speed and the voltage being constant.

(*a*) Connect as in Fig. 2, run at rated speed and voltage, and record field amperes up to 150 per cent. of the rated output.
(*b*) Plot a curve using field current as ordinates and armature current as abscissa.
(*c*) Explain
(1) why the field current increases with the load.
(2) why the rate of increase in the field current is greater for large armature currents than for small.

REFERENCES

Franklin & Esty, Direct Currents, Chap. 4–5.
Smith, Testing of Dynamos & Motors, Chap. 10.
Karapetoff, Exp. Elec. Eng., Chap, 16–17.
Bedell, D. C. & A. C. Testing, Chap. 2.

3

THE SERIES GENERATOR

The object of this experiment is to study the action of the series dynamo when operated as a generator.

1. Building Up.—The series generator cannot build up unless the external circuit is closed because the external current is also the field current and no current can flow on open circuit.

2. Characteristics.—(*a*) Connect as in Fig. 4 and measure the voltage for outputs up to 150 per cent. of the rated load.

(*b*) Determine

(1) the armature resistance.

(2) the field resistance.

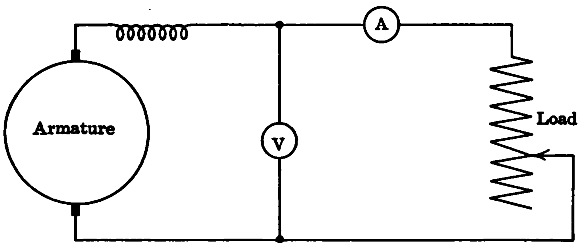


FIG. 4.

3. Plot

(*a*) the external characteristic.

(*b*) the internal characteristic.

(*c*) the *RI* drop of the armature.

(*d*) the *RI* drop of the field.

4. Explain.

(*a*) for what purpose the series generator is used commercially.

(*b*) why the characteristic curve bends to the right as the load increases.

REFERENCES

Franklin & Esty, Direct Currents, Chap. 3.
Smith, Testing of Dynamos & Motors, Chap. 7.
Bedell, D. C. & A. C. Testing, Chap. 1.

4

THE COMPOUND GENERATOR

The object of this experiment is to study the compound dynamo when operated as a generator.

1. Building Up.—The compound generator builds up in the same manner as the shunt machine.

2. Characteristics.—(*a*) Connect as in Fig. 5 and measure

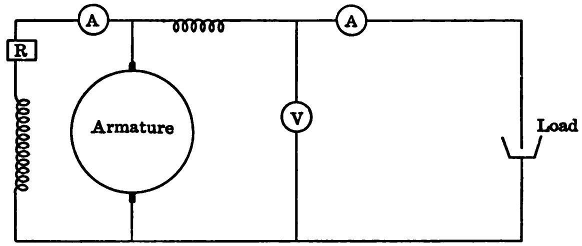


FIG. 5.

(1) terminal voltage for outputs up to 150 per cent. of the rated load, the speed and the field resistance being kept constant.
(2) the shunt field current.

(*b*) Determine
(1) the resistance of the shunt field circuit.
(2) the resistance of the armature circuit.
(3) the resistance of the series field circuit.

(*c*) Plot (1) the external characteristic.
(2) the internal characteristic.
(3) the *RI* drop in the armature.
(4) the *RI* drop in the series field.

(*d*) Define and calculate the regulation.

3. Calculation of Compounding.—The number of *turns in* the series field winding required to give a specified degree of compounding may be determined by the following methods:

(a) from the armature characteristic.

(b) by added turns.

(a) From the armature characteristic.—Determine the shunt field current required to produce the desired voltage at

(1) no-load.

(2) full-load.

Then

$$N=\frac{N_1\left(I_1-I_o\frac{E_1}{E_o}\right)}{I}$$

when N = the number of series turns required.

N_1 = the number of turns on the shunt field.

I_o = the current in the shunt field at no-load.

I_1 = the current in the shunt field at full-load.

I = the current in the series field at full-load.

E_1 = the full-load voltage.

E_o = the no-load voltage.

(b) Added Turns.—Over the shunt field wind an auxiliary field of any convenient number of turns of insulated wire, connect this auxiliary field winding to a source of e.m.f., regulate the shunt field to give the rated no-load voltage and determine the current required in the auxiliary winding to produce the desired voltage at the rated full-load armature current. Then

$$N=\frac{N_1 I_1}{I}$$

when N = the number of series turns required.

N_1 = the number of turns in the auxiliary winding

I_1 = the current in the auxiliary winding.

I = the current in the series winding at full-

4. Determination of the Number of Turns in the Shunt Field Winding.—(*a*) Measure the field current and the terminal e.m.f. at some given speed.

(*b*) Over the field coils wind an auxiliary field of a known number of turns and determine the current required in this winding to give the same e.m.f. as above when the armature is rotated at the same speed. Then

$$N = \frac{I_1 N_1}{I}$$

when N = the number of turns in the shunt field winding.
N_1 = the number of turns in the auxiliary winding.
I = the current in the shunt field winding.
I_1 = the current in the auxiliary winding.

5. Changing the Degree of Compounding.—The degree of compounding of a given dynamo may be changed by

(*a*) shunting the series field.
(*b*) changing the speed.

(*a*) Shunting the series field.—Determine the degree of compounding when the generator is run at rated speed and
(1) the entire load current flows in the series field windings.
(2) fifty per cent. of the load current flows in the series windings.

(*b*) Change of speed.—Determine the degree of compounding when run at
(1) rated speed.
(2) twenty-five per cent. above rated speed.
(3) twenty-five per cent. below rated speed.

(*Note.*—Regulate the shunt field current so that the)-load voltage is the same in each of the above tests.)

6. Explain
   (*a*) the difference between "short shunt" and "long shunt" compound dynamos.
   (*b*) why the ideal compounding is not obtained in practice.
   (*c*) the effect when the series field and the shunt field are opposed and give an example of the use of such a machine.
   (*d*) the use of the "over" compounded generator.
   (*e*) the use of the "flat" compounded generator.

REFERENCES

Franklin & Esty, Direct Currents, Chap. 3.
Smith, Testing of Dynamos & Motors, Chap. 8.
Karapetoff, Exp. Elec. Eng., Chap. 15.
Bedell, D. C. & A. C. Testing, Chap. 1.

5

CONDITIONS AFFECTING VOLTAGE

The object of this experiment is to determine the effect of certain factors on the terminal voltage of a generator.

1. Connect a shunt dynamo as in Fig. 2.

2. Brush Position.—Drive the dynamo at constant speed and with constant field excitation but with the brushes in different positions and note the voltmeter indications.

3. Magnetic Leakage.—(*a*) Note the voltage when the dynamo is driven at some desired speed and field excitation.

(*b*) Connect the pole pieces by means of iron bars or other magnetic material and note the voltage at the same speed and field excitation.

4. **Armature Reaction and Armature Drop.**—(*a*) Note the no-load voltage for a given speed and field excitation (rated values).

(*b*) Load the machine and determine the voltage at the same speed and field excitation.
(*c*) Determine the resistance of the armature circuit and calculate the proportion of the total voltage drop due to
(1) armature reaction.
(2) armature resistance.

5. **Speed.**—With constant field excitation, note the voltage when driven at different speeds up to 125 per cent. of the rated speed.

6. **Field Excitation.**—Drive the dynamo at its rated speed and take readings of the voltage for field currents varying from zero up to 150 per cent. of that required to give rated voltage at no-load.

7. Plot a curve using voltage as ordinates and having, as abscissa,

(*a*) speed.
(*b*) field amperes.

8. Explain

(*a*) how the position of the brushes affects the voltage.
(*b*) how placing an iron bar across the pole tips reduces the voltage.
(*c*) how the current in the armature affects the voltage.
(*d*) how the voltage varies as the speed changes.
(*e*) why the voltage does not vary directly as the field excitation.

(*f*) which of the above five factors combine to produce the change in voltage of a shunt generator from no-load to full-load.

REFERENCES

Franklin & Esty, Direct Currents, pp. 82–85.
Smith, Testing of Dynamos & Motors, Chap. 3.

6

PARALLEL OPERATION OF GENERATORS

The object of this experiment is to study the action of two generators when supplying a common load circuit.

1. Shunt Generators.—(*a*) Connect two shunt generators as in Fig. 6, load generator *A* to its rated capacity and regulate the voltage to the rating of the machine.

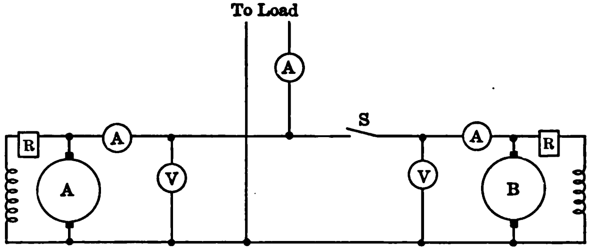


FIG. 6.

(*b*) Start generator *B* and regulate its voltage until it is eqüal to (or slightly greater than) that of *A*. Place the terminals of a voltmeter across the open switch *S*. If the voltmeter indication is zero, the switch may be closed

(*c*) After closing the switch *S*, regulate the fie
B until the machines divide the load in
portion to their ratings, increase the load t

per cent. of the combined ratings of the two machines and read

(1) voltage.

(2) amperes output of *A*.

(3) amperes output of *B*.

(*d*) Repeat the readings in (*c*) for 100 per cent., 75 per cent., 50 per cent., 25 per cent., and zero load, without changing the field resistance of either machine.

2. Compound Generators.—Connect two compound generators as in Fig. 7 and proceed as for shunt generators.

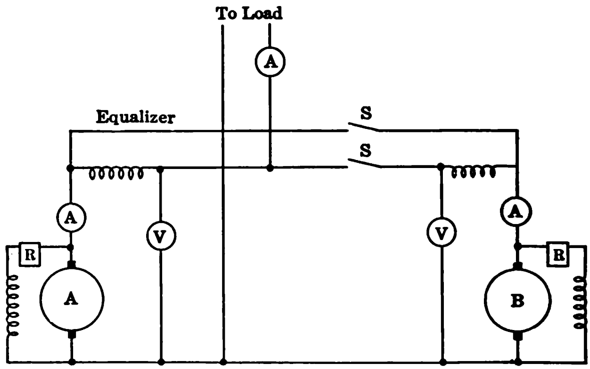


FIG. 7.

3. Explain

(*a*) why, after closing the switch *S*, the field of the shunt generator *B* must be increased to make it take a proper portion of the load.

(*b*) the action of the equalizer when compound generators are operated in parallel.

(*c*) the advantages of parallel operation.

(*d*) how to disconnect a machine from a system when operating in parallel with other generators.

(*e*) the effect when the field excitation of one machine is reduced so that its voltage is less than that of the system.

(*f*) how the load will divide between two machines, one of which is overcompounded 10 per cent. and the other 25 per cent., the voltage at no-load being equal; and how they may be made to divide the load properly.

(*g*) the effect of resistance in the equalizer circuit.

(*h*) why the equalizer circuit should not be fused.

(*i*) the effect if the circuit through the equalizer and the series field of a "dead" machine is not broken.

REFERENCES

Franklin & Esty, Direct Currents, pp. 184–198.
Smith, Testing Dynamos & Motors, pp. 118–121.
Karapetoff, Exp. Elec. Eng., Vol. 1, pp. 263–269.

7

THE SHUNT MOTOR

The object of this experiment is to study the shunt dynamo when operated as a motor and to obtain data for the construction of the performance curves.

1. Direction of Rotation.—(*a*) Connect as in Fig. 8 and note the direction of rotation.

(*b*) Reverse the field connections and note the direction of rotation.

(*c*) Reverse the armature connections and note the direction of rotation.

(*d*) Reverse both the armature and the field connections and note the direction of rotation.

2. Performance Curves by Loading.—(*a*) Load the motor by means of a Prony or a rope brake and tak readings of the following quantities for loads varying from zero to 150 per cent. of the rated capacity, the applied voltage being kept constant:

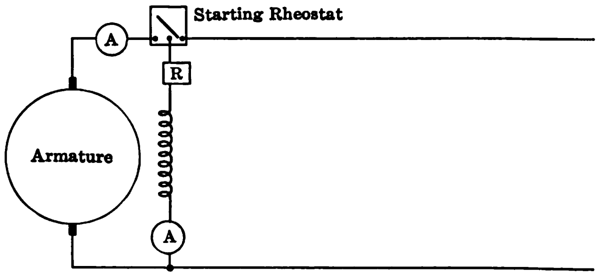


FIG. 8.

(1) speed.
(2) armature amperes.
(3) field amperes.
(4) weight on scale.

(*b*) Calculate and tabulate
(1) torque.
(2) horse-power output.
(3) efficiency.
(4) regulation.

(*c*) Using horse-power output as abscissa plot curves with the following ordinates:
(1) efficiency.
(2) speed.
(3) torque.
(4) field current.

3. Performance Curves from the Losses.—(*a*) Supply the motor with current at the rated voltage and measure ted speed)
(1) the field current at no-load.
2) the armature current at no-load.

(*b*) Determine the armature resistance.
(*c*) Calculate and tabulate, for loads up to 150 per cent. of the rated capacity, the following:
  (1) field loss.
  (2) armature copper loss.
  (3) stray power.
  (4) torque.
  (5) horse-power output.
  (6) speed.
  (7) efficiency.
(*d*) Plot
  (1) performance curves as in (2).
  (2) loss curves.

4. Explain
   (*a*) why the speed of a shunt motor falls off as the load increases.
   (*b*) how the direction of rotation of a shunt motor may be changed.
   (*c*) the meaning of the term "stray power" and how it is determined.
   (*d*) the counter e.m.f. of a motor and show how it is automatically adjusted as the load varies.
   (*e*) the relation of torque and armature current.
   (*f*) the effect of a large line resistance on the operation of the motor.

5. Define
   (*a*) speed regulation.
   (*b*) speed control and name the methods by which the speed of a shunt motor may be controlled.

REFERENCES

Franklin & Esty, Direct Currents, Chap. 4.
Karapetoff, Exp. Elec. Eng., Chap. 16.
Smith, Testing of Dynamos & Motors, Chap. 8–9.
Bedell, D. C. & A. C. Testing, Chap. 2.

8

THE SERIES MOTOR

The object of this experiment is to study the serie dynamo when operated as a motor and to obtain dat for the construction of the performance curves.

1. Connect as in Fig. 9, supply current at rated voltag and measure the following quantities for loads from 15 per cent. of the rated capacity to the highest permissibl speed:

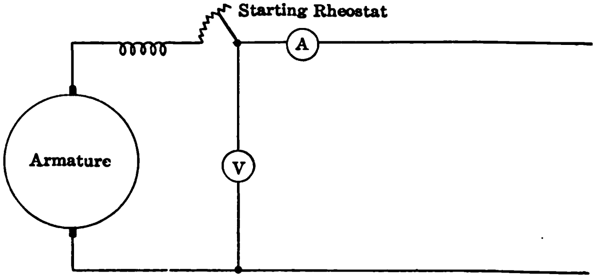


FIG. 9.

(*a*) current.
(*b*) speed.
(*c*) weight on scale.

(*Warning.*—Do not start a series motor without loa or reduce the load, while running, to a low value, as th speed will become excessive.)

2. Determine the resistance

(*a*) of the armature circuit.
(*b*) of the field circuit.
(*c*) between adjacent points of the starting rheostat

3. Calculate and tabulate for various loads

(*a*) torque.
(*b*) horse-power output.

(*c*) horse-power input.
(*d*) efficiency.

4. Plot curves, using torque as abscissa and the following as ordinates:

(*a*) armature current.
(*b*) speed.
(*c*) efficiency.
(*d*) horse-power output.

5. The copper losses of a series motor may be calculated for any given value of armature current when the combined resistance of the armature and the field circuit has been determined.

The stray power of a series motor varies over wide limits since both the speed and the field excitation change as the load changes. It may be determined, for any required speed and field excitation, by connecting the armature and the field in parallel (converting the series into a shunt motor) and to a supply circuit through suitable resistances by means of which the current in either winding may be varied independently of that in the other. Excite the field to any desired degree and vary the voltage between the terminals of the armature until the armature rotates at the required speed. The input to the armature is the sum of the stray power and the copper loss due to the resistance of the armature winding.

6. Explain

(*a*) the classes of service to which the series motor is adapted.
(*b*) the law by which the torque of a series motor varies.
(*c*) why the upper part of the torque curve dc follow this law.

(*d*) the variation of the losses in a series motor the load changes.
(*e*) the law of maximum efficiency (the consta losses equal the variable losses) for the seri motor.

REFERENCES

Franklin & Esty, Direct Currents, Chap. 4.
Karapetoff, Exp. Elec. Eng., Chap. 16.
Smith, Testing of Dynamos & Motors, Chap. 10.
Bedell, D.-C. & A.-C. Testing, Chap. 2.

9

THE COMPOUND MOTOR

The object of this experiment is to determine the spee torque characteristics of the compound motor.

1. Connect as in Fig. 10.

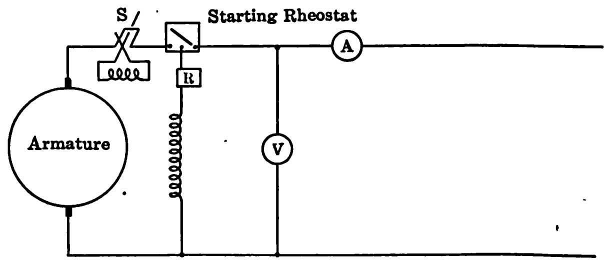


FIG. 10.

With the switch *S* closed in the upper position, lo the motor by means of a Prony or a rope brake and dete mine, for armature currents up to 150 per cent. of the fu load rating, the following:

(*a*) speed.
(*b*) torque.

2. Repeat (1) with the switch closed in the lower position.

3. Plot curves from the data in (1) and (2) using torque as abscissa and speed as ordinates.

4. Explain

(*a*) why the cumulative compound motor is adapted to the driving of machine tools such as shears and punches.

(*b*) to what class of service the differential compound motor is adapted.

(*c*) how the differential compound motor may be made to give a good starting torque.

(*d*) the relation between armature current and torque in (1) the cumulative compound motor, (2) the differential compound motor.

5. Compare the starting torque of each of the compound motors with that of the shunt and of the series motor.

REFERENCES

Franklin & Esty, Direct Currents, Chap. 4–5.
Smith, Testing of Dynamos & Motors, Chap. 10.
Karapetoff, Exp. Elec. Eng., Chap. 16–17.
Bedell, D.-C. & A.-C. Testing, Chap. 2.

10

STATIC TORQUE

The object of this experiment is the determination of the static torque of a motor.

1. Connect a shunt or a series motor as in Fig. 11, clamp a brake on the pulley so the armature cannot rotate and measure the pull on a scale for ascending and for descending values of armature current up to 150 p

cent. of the rated capacity, the field excitation being kept constant.

2. Repeat (1) for different field excitations.
3. (*a*) Calculate the torque in foot pounds.

   (*b*) Plot curves using armature current as ordinates and torque as abscissa.

4. Explain

   (*a*) the meaning of the term "torque."
   (*b*) what factors determine the torque of a motor.

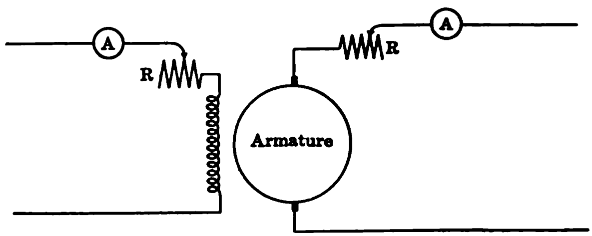


FIG. 11.

   (*c*) the reason for the difference in shape of the torque curve for a series motor and that for a shunt motor.
   (*d*) why, in the series motor, the torque curve approximates a straight line for large loads.
   (*e*) why the static torque is not developed at the pulley when the motor is running.
   (*f*) why the torque is not proportional to field excitation (the armature current remaining constant).

REFERENCES

Franklin & Esty, Direct Currents, pp. 98–99.
Smith, Testing of Dynamos & Motors, pp. 123, 159–160.

11

CONDITIONS AFFECTING THE SPEED OF A MOTOR

The object of this experiment is to determine the effect of certain conditions on the speed of a motor.

1. Connect a shunt motor as in Fig. 8 and determine the speed of its armature.
2. Determine the speed

   (*a*) for a forward "lead" of the brushes.
   (*b*) for a backward "lead" of the brushes.
   (*c*) when the pole pieces are connected by means of a bar of iron or other magnetic material.
   (*d*) when the applied voltage is reduced to approximately one-half that in (1).
   (*e*) when the armature voltage is as in (*d*) and the field excitation as in (1).
   (*f*) when the field resistance is increased.
   (*g*) when the field resistance is decreased.

3. Explain each change of speed in (2).

State which of the above methods are used to control the speed of commercial variable speed motors.

REFERENCES

Franklin & Esty, Direct Currents, pp. 103–112.
Smith, Testing of Dynamos & Motors, Chap. 8.
Karapetoff, Exp. Elec. Eng., pp. 365–366.

12

STRAY POWER

The object of this experiment is the determination of the stray power of a dynamo and the separation of such loss into its components.

1. The stray power of a dynamo may be determined in the following ways:

(*a*) by means of an auxiliary motor.
(*b*) by running the dynamo as a motor.
(*c*) by retardation.

(*a*) By means of an auxiliary motor.—Connect as in Fig. 12 in which *G* is the dynamo the stray power of which is to be determined and

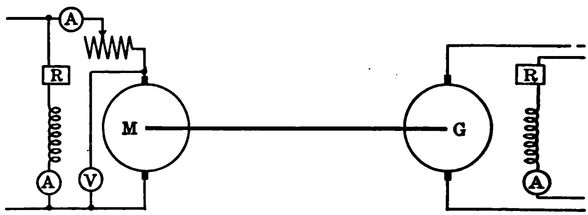


FIG. 12.

M is an auxiliary motor direct connected to the shaft of *G*. Keep the field current of the motor constant throughout the test by means of the field rheostat and regulate the speed by means of the resistance in the armature circuit.

Drive the dynamo at its rated speed, regulate its field (separate excitation) to give rated voltage and determine the watts input to the armature of the motor, *M*.

Repeat for 125 per cent., 75 per cent., 50 per cent. and 25 per cent. of rated speed, keeping the field excitation constant.

Determine the input to the motor armature over the above range of speed but with zero field excitation on the dynamo.

Disconnect the motor from the dynamo and determine the losses in the motor armature over the above range of speed.

Calculate and tabulate

(1) motor armature losses.
(2) the friction loss in the dynamo.
(3) the iron (core) loss in the dynamo.

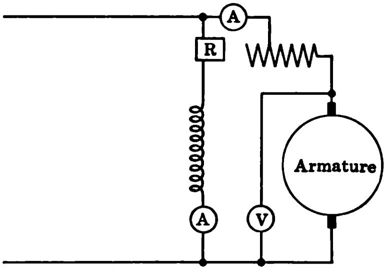


FIG. 13.

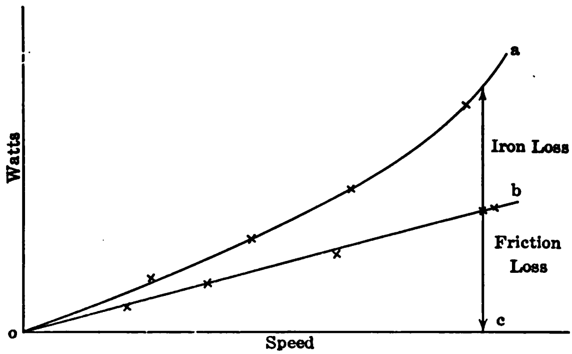


FIG. 14.

Plot

(1) the friction-loss curve.
(2) the iron-loss curve.

(*b*) By running the Dynamo as a Motor.—Connect as in Fig. 13. With constant field excitation run at various speeds from 125 per cent.

rated speed to as low a value as possible by changing the armature resistance. Read armature volts and amperes.

Calculate the stray power and plot as in Fig. 14.

A tangent to the stray-power curve drawn through the origin will separate the loss into its components of iron and friction losses; or the friction may be determined as follows:

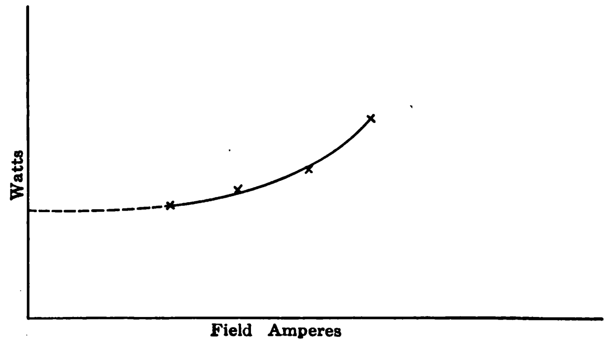


FIG. 15.

Keeping the speed constant, determine the stray power for different field excitations and plot as in Fig. 15. Extend the curve to its intersection with the axis of ordinates. The ordinate, at this intersection, is the loss due to friction at the given speed. Repeat for not less than four different speeds and, from the friction losses so determined, plot the friction-speed curve as in Fig. 14, which will divide the stray power into iron and friction losses.

(c) Retardation.—Speed up a shunt motor to approximately 125 per cent. of the rated speed. Break the armature circuit and, at the same instant, bring the field rheostat to the position that will give the desired field excitation. Determine the instantaneous speed, at regular intervals, as the armature slows down.

Measure the watts input to the armature at this excitation and for any desired or convenient speed; determine the resistance of the armature winding and calculate the stray power.

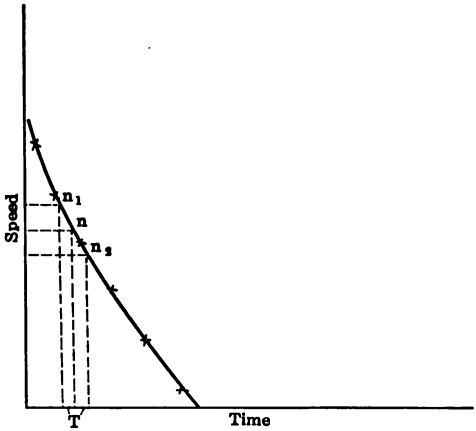


FIG. 16.

Plot the speed-time or retardation curve as in Fig. 16.

From the retardation curve find speeds, n_1 and n_2, before and after the speed, n, for which the wattage was determined. Select n_1 and n_2 so that $\frac{n_1+n_2}{2}=n$.

Then

$$\text{watts loss at speed } n = K\frac{n_1^2-n_2^2}{T}$$

when K is a constant proportional to the moment of inertia of the rotating parts.

and T is the time required for the rotating parts to decrease from speed n_1 to n_2.

After the value of K is determined from the above equation, the loss at any required speed may be calculated and the loss curve plotted as in Fig. 17.

Take data and construct the retardation curve for

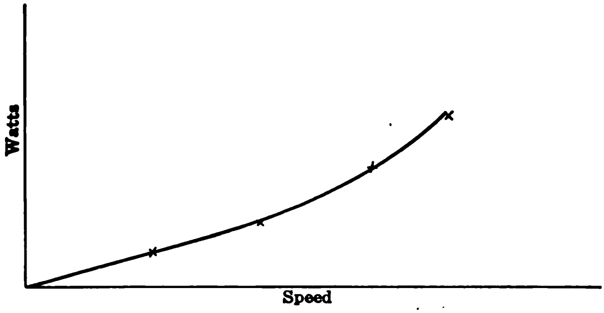


FIG. 17.

(1) normal field current.
(2) field current 25 per cent. above normal.
(3) field current 25 per cent. below normal.
(4) field current zero.

From the above curves and one wattage measurement determine and tabulate, for not less than five speeds, the loss for each degree of excitation.

Plot

(1) watt-speed curve for each degree of excitation.
(2) watt-excitation curve showing the variation of the losses with field excitation but for constant (normal) speed.

(*Note.*—The methods outlined above for determining the stray power of a dynamo are not limited to the shunt machine but are equally applicable to the series, and the compound dynamo and to alternating current machines.)

2. Iron Losses.—The iron (core) losses as determined by either of the above methods, may be separated into eddy-current and hysteresis loss in the following manner:

Iron loss = hysteresis loss + eddy-current loss.

or, $W = k_h n + k_e n^2$.

Dividing this expression by n,

$$\frac{W}{n} = k_h + k_e n$$

which is an equation of a straight line between $\frac{W}{n}$ and n,

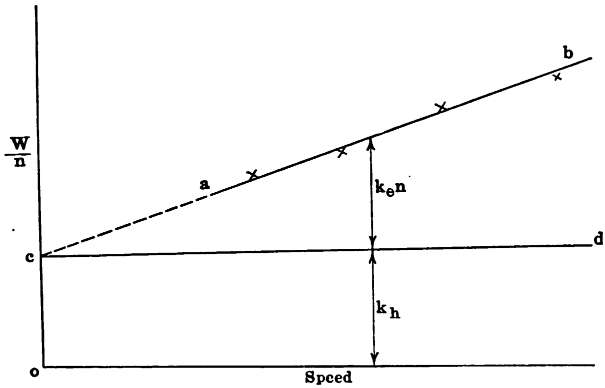


FIG. 18.

when

n = speed.

k_h = a constant porportional to the hysteresis loss.

k_e = a constant porportional to the eddy-current loss.

W = the total iron loss.

From the iron loss curve find the losses for a series of speeds and plot as in Fig. 18. Extend the line, *ab*, to the axis of ordinates and through the intersection draw a horizontal line. The ordinate, *oc*, multiplied by the speed, *n*, gives the hysteresis loss at that speed; the ordinate between *ab* and *cd*, multiplied by the speed at which the ordinate was measured, gives the eddy-current loss at that speed.

3. Explain

(*a*) the meaning of the term "stray power" and how it varies (1) in a motor, (2) in a generator.
(*b*) how the friction loss varies.
(*c*) how the iron losses vary.
(*d*) the determination of the "stray power" of a (1) series motor, (2) compound motor.

REFERENCES

Franklin & Esty, Direct Currents, pp. 129–132.
Karapetoff, Exp. Elec. Eng., Chap. 17.
Smith, Testing of Dynamos & Motors, pp. 210–227.
Smith, Alternating Currents, pp. 231–233.
Bedell, D. C. & A. C. Testing, Chap. 2.
Foster's Handbook.
Standard Handbook.

13

ARMATURE MAGNETIZATION

The object of this experiment is to study the magnetizing action of the armature current.

1. Supply the armature of a shunt dynamo with approximately full-load current, the field circuit being kept open.

Vary the position of the brushes through 180 electrical degrees and note the effect on the armature.

2. Connect the field terminals of the dynamo through a voltmeter, block the armature to prevent rotation, supply the armature with current as in (1) and note the deflection of the voltmeter when the armature circuit is suddenly broken.

Repeat for not less than twenty positions of the brushes over approximately 180 electrical degrees.

3. Plot a curve using electrical degrees (or commutator segments) as abscissa and voltmeter deflections as ordinates.

4. Explain

(*a*) the action of the armature in (1).
(*b*) the deflection of the voltmeter when the armature circuit is broken as in (2).
(*c*) why there is no deflection of the voltmeter when the armature circuit is broken with the brushes in the "neutral" position.
(*d*) why the voltmeter deflection is not the same for all positions of the brushes.
(*e*) why the terminals of the voltmeter must be reversed when the brushes pass the "neutral" position.
(*f*) the meaning of the term "neutral" position.

REFERENCES

Franklin & Esty, Direct Currents, pp. 93, 151–161.
Smith, Testing of Dynamos & Motors, pp. 62–64.
Sheldon & Hausmann, Direct Currents, Chap. 5.
Karapetoff, The Magnetic Circuit, Chap. 9.
Steinmetz, Elements, pp. 187–188.

14

MAGNETIZATION CURVES

The object of this experiment is to obtain data for the construction of the magnetization curve at no-load and at full-load.

1. At No-load.—Connect the dynamo to be tested as in Fig. 19, the armature circuit being open and the field separately excited. Drive the armature at con stant (rated) speed and take readings of terminal voltage for

(*a*) increasing values of field current.
(*b*) decreasing values of field current.

2. At Full-load.—Connect as in (1) and close the armature circuit through a variable resistance. With

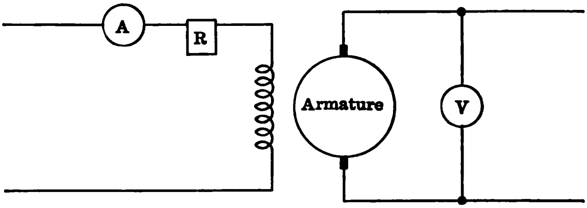


FIG. 19.

a small field excitation, adjust the resistance of the armature circuit until the rated full-load current flows and read field current and terminal e.m.f.

Increase the field excitation, simultaneously increasing the resistance of the armature circuit so that the armature current remains at the rated full-load value, and again read field amperes and terminal volts.

Repeat for small increases of field excitation until the field approaches saturation.

3. Construct

(*a*) the no-load magnetization curve.
(*b*) the full-load magnetization curve.

4. Explain

(*a*) why the magnetization curves for ascending and for descending values of field current do not coincide.
(*b*) how the reading may be corrected for any variation in speed.

(c) why the lower part of the magnetization curve is approximately straight while the upper part bends to the right.
(d) why the descending no-load curve cuts the axis of ordinates above the origin and what use is made of this fact in the practical operation of dynamos.
(e) why the machine should be separately excited.

REFERENCES

Franklin & Esty, Direct Currents, pp. 384–386.
Smith, Testing of Dynamos & Motors, pp. 38–45.
Karapetoff, Exp. Elec. Eng., Chap. 8.
Bedell, D. C. & A. C. Testing, Chap. 1.
Steinmetz, Elements, pp. 188–190.

15

MAGNETIC LEAKAGE

The object of this experiment is to determine the ratio of the total flux produced by the field windings to that effective in producing electromotive force in the armature conductors.

1. Connect as in Fig. 20 for a bi-polar dynamo. *A* is a coil of insulated wire wound over the field winding near the yoke and *B* is a coil, having the same number of turns as *A*, wound on the armature in such a position that the flux passing through the armature passes through the coil. The terminals of the coils, *A* and *B*, should be connected to a low-reading voltmeter by means of a double pole, double throw switch.

For multi-polar dynamos connect as in Fig. 21, making the number of turns in coil *A* twice the number in coil *B*.

2. Excite the field weakly from a suitable source, connect coil *A* to the voltmeter and note the throw of the pointer when the armature circuit is broken.

2. Length of the Air Gap.—Through the origin and parallel to the straight portion of the hysteresis loop, draw the line *ab*. The ratio of the abscissa of any point on this line and the ordinate of the same point is the

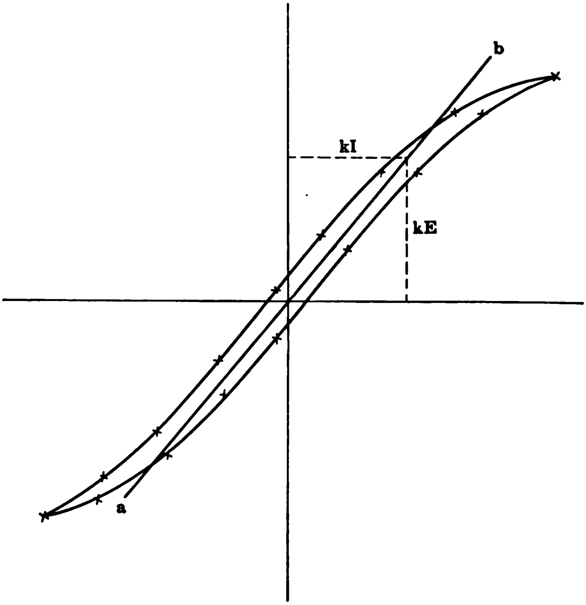


FIG. 22.

ratio of, and may be substituted for $\frac{I}{E}$ in the following expression:

$$l=\frac{1.0472NZAp_1n}{10^{10}p_2}\cdot\frac{I}{E}$$

when l = the length of the air gap in centimeters.
N = the number of turns per pair of field poles.
Z = the total number of armature conductors.
n = armature revolutions per minute.

A = the sectional area of the air gap in square centimeters.

p_1 = the number of field poles.

p_2 = the number of parallel paths through which the current may flow.

I = the field current (amperes).

E = voltage generated in the armature.

3. (*a*) Determine the length of the air gap.
   (*b*) Derive the formula for the length of the air gap.
4. Explain
   (*a*) why the hysteresis curve is a loop.
   (*b*) why the sides of the loop bend over as the excitation increases.
   (*c*) how you would judge the quality of iron from its hysteresis loop.
   (*d*) the effect of the length of the air gap on the shape of the hysteresis loop.
   (*e*) the effect of the length of the air gap on the magnetizing force (ampere turns) required for a given voltage in a given machine.

REFERENCES

Franklin & Esty, Direct Currents, pp. 279–281.
Karapetoff, Exp. Elec. Eng., Chap. 8–9.
Sheldon & Hausmann, Direct Currents, pp. 38–40.

17

FLUX DISTRIBUTION IN THE AIR GAP

The object of this experiment is to determine the distribution of the flux in the air gap when the armature is unloaded and when it is loaded.

1. Single Pilot Brush.—(*a*) Support an auxiliary brush, *B*, (Fig. 23) so that it will make contact with the commutator and that its position, relative to the main brushes, AA, may be varied by regular steps.

(*b*) Drive the dynamo at its rated speed and with such field excitation as will give rated voltage. Vary the position of the auxiliary brush, by regular steps, through approximately 180 electrical degrees, and take a voltmeter reading for each position. The voltmeter reading is the sum of the voltages generated in the armature

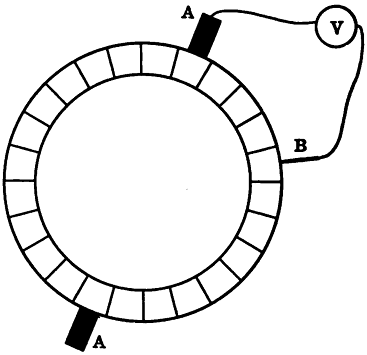


FIG. 23.

coils between the auxiliary brush and the main brush to which the voltmeter is connected.

(*c*) Repeat (*b*) when the armature is carrying full-load (rated) current.

2. Double Pilot Brush.—Replace the single brush in (1) with two brushes, insulated from each other and so spaced that the distance from center to center of the brushes is equal to that from center to center of two adjacent commutator bars. (Fig. 24.) Vary the position of the pilot brushes as in (1) and note the voltmeter indications.

3. With e.m.f. as ordinates and electrical degrees (or commutator segments) as abscissa, construct a diagram showing the distribution of the flux for

(*a*) no-load.
(*b*) full-load.

indicating on the diagram the position of the pole and of the main brushes.

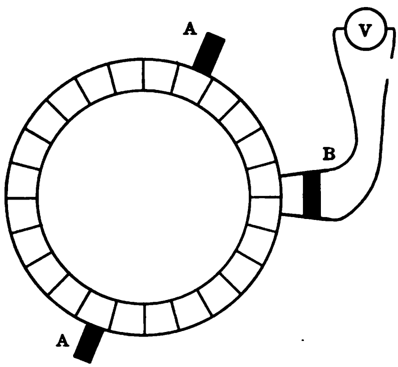


FIG. 24.

4. Explain
(*a*) how to determine the proper position of the brushes.
(*b*) why the relative position of the pole and the brush is not the same at full-load as at no-load.
(*c*) why the distribution of the flux in the air gap is not the same at full-load as at no-load.
(*d*) how the voltage measured is an indication of the magnitude of the flux.

REFERENCES

Karapetoff, Exp. Elec. Eng., pp. 182–184.
Steinmetz, Elements, pp. 177–186.

18

BOOSTER ACTION

The object of this experiment is to study the booster dynamo (1) when used to compensate for line drop, (2) when used in connection with a storage battery to equalize the load on a generator.

1. Line Booster.—Connect as in Fig. 25, the booster being a series generator (whose armature conductors are sufficiently large to carry the entire line current) driven by a shunt motor or other constant speed engine.

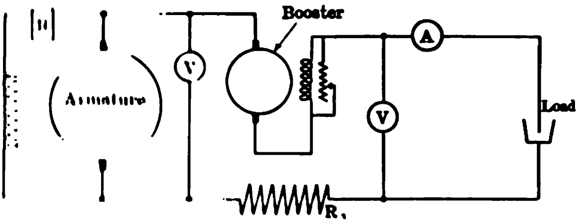


FIG. 25.

The resistance, R_1, is a rheostat, the drop through which represents that in a long feeder for which the booster is to compensate.

(a) Load the system by means of a resistance, regulate the shunt around the field of the booster so that the voltage at the load terminals is equal to that at the terminals of the generator. Vary the load on the generator from zero to 125 per cent. of the rated capacity reading, for each step,
  (1) e.m.f. at generator terminals.
  (2) e.m.f. at load terminals.
  (3) line amperes.

(b) Using line current as abscissa, plot a curve having as ordinates

(1) generator voltage.
(2) load voltage.

2. Battery Booster.—Connect as in Fig. 26, the booster being a differentially compounded generator. Regulate the shunt field of the booster so that the booster voltage will be approximately one-fifth that of the battery. Regulate the shunt around the series (booster) field so that this field will neutralize the shunt field at the average load to be delivered to the receiving circuit.

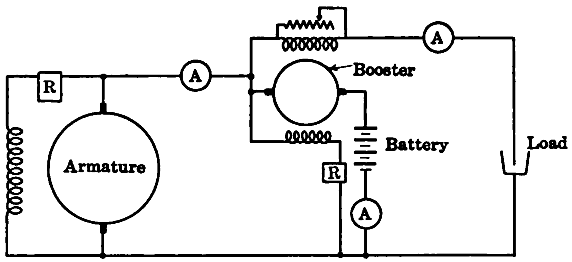


FIG. 26.

Vary the load, by small steps, from zero to the maximum, and read

(*a*) line amperes.
(*b*) battery amperes (to or from).
(*c*) generator amperes.

Repeat, varying the load as rapidly as possible or by sudden increments.

Plot curves showing the relation between (*a*), (*b*) and (*c*).

3. Explain

(*a*) the action of the line booster.
(*b*) the action of the battery booster.

REFERENCES

Franklin & Esty, Direct Currents, pp. 256–265.
Smith, Testing of Dynamos & Motors, pp. 296–306.
Karapetoff, Exp. Elec. Eng., Vol. 2, pp. 414–420.
Sheldon & Mason, D.-C. Machinery, Chap. 8.
Lyndon, Storage Batteries, Chaps. 31–2–3.
Crocker, Electric Lighting, pp. 424–428.

19

HEAT TEST

The object of this experiment is to determine the rise in temperature of the different parts of a dynamo under load conditions.

1. Determine the resistance of the

(*a*) armature winding.
(*b*) field winding.

2. Load the dynamo as either a generator or a motor by means of a brake (motor), a water rheostat (generator) or by any of the opposition methods (either motor or generator).

Maintaining the speed, the voltage and the armature current at the rated values, make periodical determinations of the following:

(*a*) temperature of the air.
(*b*) temperature of the field windings.
(*c*) temperature of the leading pole tip.
(*d*) temperature of the lagging pole tip.
(*e*) temperature of the bearings.
(*f*) temperature of the armature core.
(*g*) resistance of the field windings.
(*h*) resistance of the armature winding.

Using a temperature coefficient of 0.0042 calculate temperature rise of

(*a*) the field windings.
(*b*) the armature winding.

With time as abscissa and temperature as ordinates, plot curves showing the temperature rise of each of the above parts.

Correct the observed temperature rise to the standard temperature of 25° C. (*i.e.*, calculate the rise that would occur if the temperature of the air were 25° C.) by adding or subtracting one-half of 1 per cent. for each degree that the air is below or above the standard temperature.

4. Explain

(*a*) why the trailing and the leading pole tips do not have the same temperature.
(*b*) why the rise in the temperature of the coils, as observed, is different from that calculated from the change in resistance.
(*c*) how the copper loss changes with increased temperature.
(*d*) how the iron losses change with increased temperature.

REFERENCES

Franklin & Esty, Direct Currents, pp. 148–150.
Karapetoff, Exp. Elec. Eng., Chap. 18.

20

THREE-WIRE SYSTEM

The object of this experiment is to determine the voltage relations in a three-wire system.

1. (*a*) Connect a rotary converter as in Fig. 27 or two similar shunt dynamos as in Fig. 28.

(*b*) Load the three-wire system so that the indi tions of the ammeters in the outside wires are equal.

(*c*) Decrease the load on one side of the system to zero, recording the ammeter and the voltmeter indications for not less than five steps.

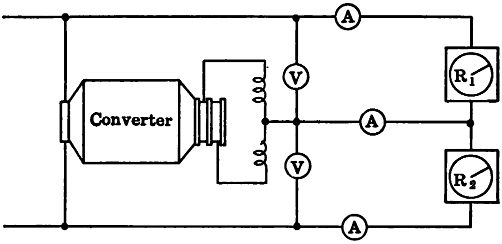


FIG. 27

(*d*) Reduce the load on the other side of the system in a similar manner.

2. Using total load on the system as abscissa, plot curves showing the voltage between each outside wire and the neutral.

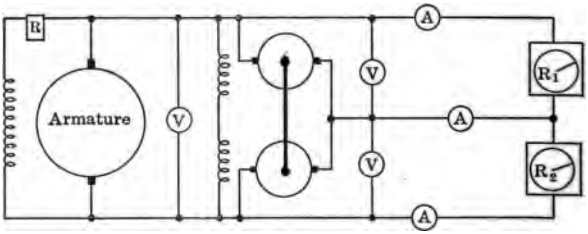


FIG. 28.

3. Explain

(*a*) why the current in the neutral wire is zero when the currents in the outside wires are equal.

(*b*) the advantages of the three-wire system.

(*c*) the effect of the inductance coil in the rotary converter connection.
(*d*) why the regulation of the three-wire generator is better than that of two shunt dynamos in series.
(*e*) how the three-wire generator may be compounded.

REFERENCES

Franklin & Esty, Direct Currents, pp. 269–275.
Smith, Testing of Dynamos & Motors, pp. 284–292.
Karapetoff, Exp. Elec. Eng., Vol. 1, pp. 291-293.

21

THE MOTOR-GENERATOR AND THE DYNAMOTOR

The object of this experiment is to determine the regulation and the efficiency of a motor-generator or of a dynamotor.

1. Keeping the voltage at the terminals of the motor of a motor-generator constant, run the set at rated speed and determine, for loads up to 125 per cent. of rated capacity:

(*a*) input.
(*b*) output.
(*c*) the voltage at the generator terminals.

2. Repeat with constant field excitation of the motor, determining, in addition to (*a*), (*b*) and (*c*) of (1), the speed of the motor.

3. Repeat using a dynamotor instead of a motor-generator.

4. With current output as abscissa plot curves with the following ordinates:

(*a*) efficiency.
(*b*) voltage of generator.
(*c*) speed of motor.

5. Calculate the per cent. regulation of the
   (*a*) motor.
   (*b*) generator with constant speed.
   (*c*) generator with constant field excitation of the motor.

6. Explain
   (*a*) why the efficiency is greater in a motor-generator, at constant speed than at constant excitation of the motor field.
   (*b*) why the voltage regulation of the generator is better at constant speed than at constant excitation of the motor field.
   (*c*) why the efficiency of the dynamotor is greater than that of the motor-generator.
   (*d*) the structural differences in the motor-generator and the dynamotor.
   (*e*) the comparative advantages of the motor-generator and the dynamotor.
   (*f*) by means of a diagram, the connections for using the dynamotor as a three-wire generator.

REFERENCES

Franklin & Esty, Direct Currents, 70–71.
Smith, Testing of Dynamos & Motors, pp. 292–296.
Sheldon & Mason, D.-C. Machinery, Chap. 8.

22

INSULATION RESISTANCE

The object of this experiment is the determination of the resistance of insulation.

1. Connect as in Fig. 29. When the single-pole, double-throw switch is closed in the upper position, the voltmeter is connected directly across the supply lines; when closed in the lower position, the insulation to be tested is connected across the supply lines in series with the voltmeter.

(*Note.*—The voltage used in this test should not be less than the normal working pressure of the apparatus

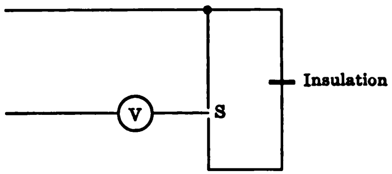


FIG. 29.

tested and the voltmeter should have a high resistance. A Weston voltmeter having a resistance of from 60,000 to 80,000 ohms is suitable.)

$$R = R_v \frac{(E_1 - E_2)}{E_2}$$

when R = the resistance of the insulation under test.

R_v = the resistance of the voltmeter.

E_1 = voltmeter indication when connection is made directly across the supply lines.

E_2 = the voltmeter indication when the voltmeter and the insulation are connected in series.

2. Determine the resistance of the insulation between

(*a*) the armature winding of the assigned dynamo and the frame.

(*b*) the field winding of the assigned dynamo and the frame.

(*c*) the wires of the supply circuit.

(*d*) the wire of the supply circuit and the ground

3. Explain why a high-resistance voltmeter is necessary in this experiment.

REFERENCES

Smith, Testing of Dynamos & Motors, pp. 255–257.
Karapetoff, Exp. Elec. Eng., Vol. 2, pp. 82–88.
Standard Handbook.
Foster's Handbook.

23

THE VARIABLE SPEED MOTOR

The object of this experiment is to study the operating characteristics of a variable speed shunt motor.

1. Load a variable speed shunt motor to its rated capacity at its lowest speed and determine
   (*a*) input.
   (*b*) output.
   (*c*) speed.

Reduce the load 50 per cent. and take a second set of readings.

Measure the speed at no-load.

2. Repeat (1) for different speeds up to the maximum allowable.
3. Determine for each speed
   (*a*) the efficiency at full-load.
   (*b*) the regulation.
4. Explain
   (*a*) by means of a diagram, the construction and the operation of the motor tested.
   (*b*) the general principles of other variable speed (commercial) motors.

REFERENCES

Franklin & Esty, Direct Currents, pp. 105–112.
Smith, Testing of Dynamos & Motors, pp. 128–130.
Karapetoff, Exp. Eng., Vol. 1, pp. 291–293.

ALTERNATING CURRENTS

1

Properties of a Circuit Carrying an Alternating Current

The object of this experiment is to show the effect of resistance and of reactance in a circuit carrying an alternating current.

Part 1.—Resistance and Reactance in Series.

1. (*a*) Connect an inductive and a non-inductive resistance in series, as shown in Fig. 30, and determine

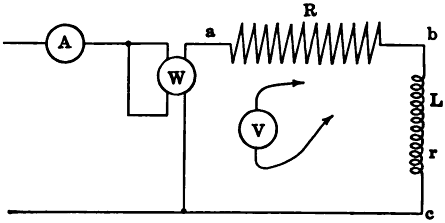


Fig. 30.

the following when the circuit is supplied with current at 60 cycles and a suitable voltage:

(1) amperes.
(2) watts.
(3) voltage *ac*.
(4) voltage *ab*.
(5) voltage *bc*.

(*b*) Change the value of the inductance and t: a second set of readings.

(*c*) Change the value of the resistance and take a third set of readings.

(*Note.*—The inductive resistance should, preferably, be a coil without iron and so constructed that its inductance may be changed without changing the ohmic resistance of the circuit.)

2. Replace the inductive resistance with a coil having a removable iron core and take two sets of

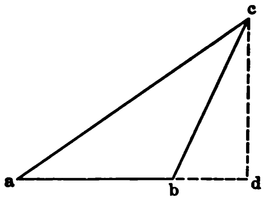


FIG. 31.

readings—one with the iron core in the coil and one with it removed—the current or the applied voltage being the same in both cases.

3. Determine the ohmic resistance of the circuits in (1) and in (2).

4. Replace the inductance coil in (1) with a condenser and take readings for two different values of capacity.

5. Change the frequency and repeat (1), (2) and (4).

6. Construct the voltage triangle from the data obtained in (1), (2), (4) and (5) as in Fig. 31. The projection, *ad*, of the line, *ac*, on the line, *ab*, should al approximately, $\frac{W}{I^2}$.

. Discuss the changes in the meter indications n

(*a*) the inductance is changed.

(*b*) the capacity is changed.
(*c*) the frequency is changed.
(*d*) the iron core is removed from the coil.

8. Calculate

(*a*) the value of the non-inductive resistance.
(*b*) the ohmic resistance of the inductive coil.
(*c*) the inductance (or capacity) of the circuit.

9. Explain

(*a*) the meaning of the lines *bd* and *cd* in the voltage diagram.
(*b*) how the presence of iron affects the inductance of the circuit.
(*c*) why the ohmic resistance of the circuit in (2) is less than $\frac{W}{I^2}$.

10. Compare

(*a*) the terminal voltage and the power lost when an alternating current flows in an inductive circuit without iron, with the terminal voltage and the power lost when a direct current of the same value flows in the same circuit.
(*b*) the terminal voltage and the power lost when an alternating current flows in a coil without iron, with the terminal voltage and the power lost when the same value of alternating current flows in the same coil but with an iron core.

Part 2.—Resistance and Reactance in Parallel.

1. (*a*) Connect an inductive and a non-inductive resistance in parallel, as shown in Fig. 32, and note the indications of the three ammeters when connection is made to a 60-cycle alternating-current system of proper voltage.

(*b*) Change the value of the inductance and take a second set of readings.

(*c*) Change the value of the resistance and take a third set of readings.

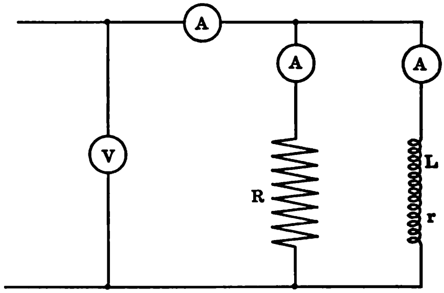


FIG. 32.

2. Replace the inductance with a capacity and repeat (1).
3. Repeat (1) and (2) for a different frequency.
4. Construct the current triangle.
5. Determine
   (*a*) the resistance of the circuit.
   (*b*) the impedence of the circuit.
   (*c*) the inductance (or capacity) of the circuit.
   (*d*) the power factor of the circuit and that of the inductance coil.
6. Explain
   (*a*) why the current in the line is not the sum of the currents in the branches.
   (*b*) what practical condition the above circuit represents.
   (*c*) the following equation:

$$\frac{1}{Z}=\sqrt{\left(\frac{R_1}{Z_1^2}+\frac{R_2}{Z_2^2}\right)^2+\left(\frac{X_1}{Z_1^2}+\frac{X_2}{Z_2^2}\right)^2}$$

when R_1 and R_2 are the resistances of two coils connected in parallel.

X_1 and X_2 are the reactances of the two coils.

Z_1 and Z_2 are the impedences of the two coils.

Z is the impedence of a single coil which is equivalent to the two coils in parallel.

(*d*) how the resistance and the reactance of the equivalent coil may be determined.

Part 3.—Voltage Resonance.

1. Connect a non-inductive resistance, an inductive resistance and a condenser as in Fig. 33, supply an alternating current and read the following for different values of inductance:

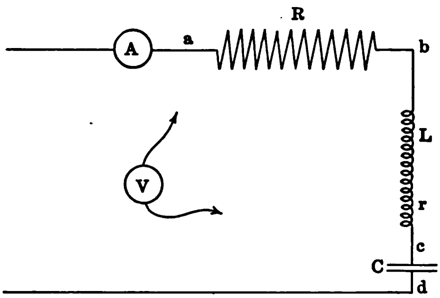


FIG. 33.

(*a*) amperes.
(*b*) voltage *ab*.
(*c*) voltage *bc*.
(*d*) voltage *cd*.
(*e*) voltage *ac*.
(*f*) voltage *ad*.

2. Repeat (1) varying the capacity.
3. Repeat (1) varying the frequency.
4. Construct the voltage triangle, *abc*,

from c drop a perpendicular, cd, proportional to Ecd. The line, ad, should be proportional to Ead, the applied voltage.

5. Calculate the value of
   (*a*) the ohmic resistance of each part of the circuit.
   (*b*) the inductance of the circuit.
   (*c*) the capacity of the circuit.
   (*d*) the reactance of the circuit.
   (*e*) the power factor of the circuit and of each part.

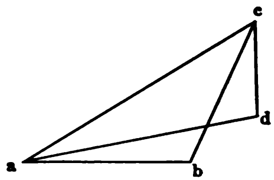


FIG. 34.

6. Construct a curve with inductance, capacity or frequency as abscissa and
   (*a*) current as ordinates.
   (*b*) power factor as ordinates.
7. Explain
   (*a*) the effect of varying the frequency.
   (*b*) the effect of varying the inductance.
   (*c*) the effect of varying the capacity.
   (*d*) the advantages and the disadvantages of voltage resonance.
   (*e*) how the voltage over a part of the circuit may be greater than that over the whole.

Part 4.—Current Resonance.

. Connect a non-inductive resistance, an inductive stance and a capacity to A.-C. mains as indicated in . 35. Vary the inductance and read volts and amperes.

:. Repeat (1) varying the capacity.

3. Repeat (1) varying the frequency.

4. Determine the power factor of the circuit for each value of inductance, capacity or frequency.

5. Plot a curve using inductance, capacity or frequency as abscissa and

(*a*) line current as ordinates.
(*b*) power factor as ordinates.

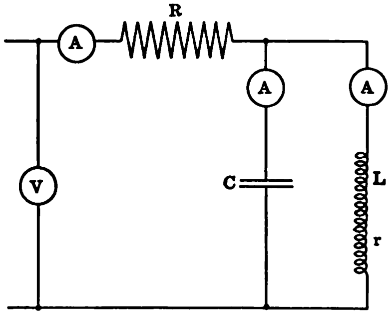


FIG. 35.

6. Explain

(*a*) the advantages of current resonance.
(*b*) the disadvantages of current resonance.
(*c*) how the line current may be less than the sum of the currents in the branches.
(*d*) how current resonance may be obtained in transmission lines.

REFERENCES

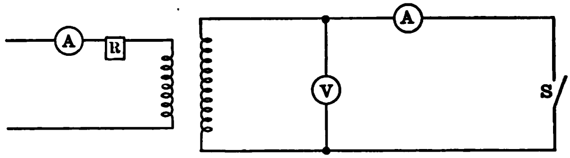
Franklin & Esty, Alternating Currents, Chap. 4.
Karapetoff, Exp. Elec. Eng., Chap. 5.
Karapetoff, The Electric Circuit, Chaps. 4–7.
Steinmetz, A.-C. Phenomena, Chap. 9.
Steinmetz, Elements, pp. 48–58.
Smith, Alternating Currents, Chap. 1–5.
Foster's Handbook.
Standard Handbook.

2

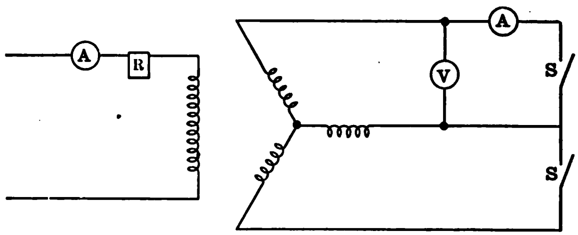
THE ALTERNATING-CURRENT GENERATOR

The object of this experiment is to obtain data for the construction of the saturation curve and of the short-circuit curve, and for the calculation of the efficiency and the regulation of an alternating-current generator.

1. The Saturation Curve.—Connect an alternator as in Fig. 36 (switches open) and take readings of the



Single Phase



Three Phase

FIG. 36.

e.m.f. of the armature (running at rated speed) for field currents varying from zero to 150 per cent. of normal excitation or until the field approaches saturation.

2. The Short-circuit Curve.—Connect an alternator as in Fig. 36 (switches closed), the armature being short-circuited through a suitable ammeter. Vary the field excitation (beginning at zero) so as to obtain values of armature current up to 150 per cent. of full-load.

3. Determine the resistance of the armature.

4. Synchronous Reactance.—Divide the open-circuit voltage (as taken from the saturation curve) by the short-circuit amperes produced by the same value of field excitation. This gives the synchronous impedence from which the synchronous reactance may be determined, using the armature resistance as determined in (3).

$$X = \sqrt{Z^2 - R^2}$$

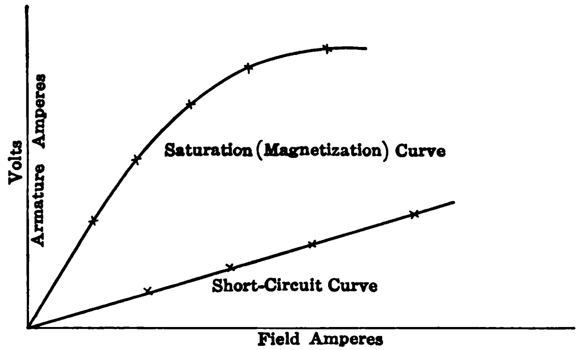


FIG. 37.

5. Regulation.—The regulation of an alternator may be determined by (*a*) loading, (*b*) the e.m.f. method, (*c*) the m.m.f. method.

(*a*) Loading.—Load the alternator (the load circuit having some specified power factor) to its rated capacity, the speed and voltage of the machine being at the rated values.

Determine the voltage when the load is reduced to zero, the speed and the field excitation remaining constant. (See A.I.E.E. Rules.)

(*b*) E.M.F. Method.—From the short-circuit curve and the saturation curve find the voltage I quired to force full-load current through the short-circuited armature. The no-load voltage is the vector sum of this e.m.f. and the rated voltage of the alternator, taking account of the power factor of the load circuit.

$$E = \sqrt{(E_1 \cos\phi + RI)^2 + (E_1 \sin\phi + XI)^2}$$

when E = the no-load voltage.
E_1 = the rated voltage of the alternator.
RI = resistance drop in the alternator armature.
XI = reactance drop in the alternator armature.
$\cos \phi$ = power factor of the load circuit.

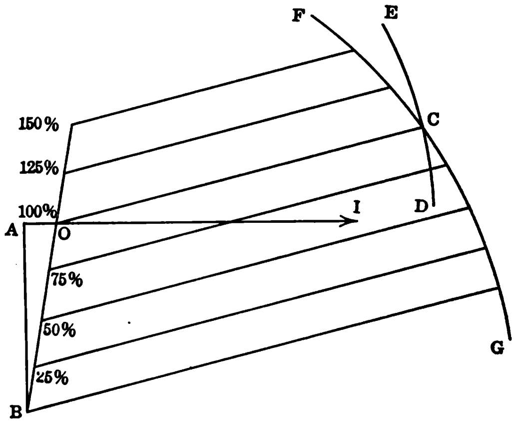


FIG. 38.

(c) M.M.F. Method.—Find, from the saturation curve, the field current required to produce a voltage equal to the total ohmic drop in the circuit ($E_1 \cos \phi + RI$) and, from the saturation curve and the short-circuit curve, the field current required to produce a voltage equal to the total reactive drop of the circuit ($E_1 \sin \phi + XI$). Then

$$I=\sqrt{I_1^2+I_2^2}$$

when I = the field current required to produce rated voltage at full-load.

I_1 = the field current required to produce a voltage equal to the total ohmic drop of the circuit.

I_2 = the field current required to produce a voltage equal to the total reactive drop of the circuit.

From the saturation curve find the open-circuit voltage when the field current equals I.

6. Graphical.—With O (Fig. 38) as a center and a radius proportional to the rated e.m.f. strike an arc, ECD. Through O draw the current vector, I. Lay off OA proportional to the resistance drop, RI, and AB proportional to the reactance drop, XI. Draw OC to the intersection with the arc, ECD, so that the cosine of the angle, COI, equals the power factor of the load circuit. BC is proportional to the generated or no-load voltage.

With B as a center and a radius equal to BC, strike a second arc, FCG. Divide OB into four equal parts and lay off two similar divisions beyond O, thus obtaining points representing 25 per cent., 50 per cent., 75 per cent., 100 per cent., 125 per cent. and 150 per cent. of the rated capacity. From these points and from B draw lines parallel to OC to their intersection with the arc, FCG. The lengths of these parallel lines are proportional to the terminal voltages at the given percentages of load.

7. Efficiency.—The efficiency of an alternator may be determined (a) by loading, (b) from the losses.

(a) Loading.—Load the alternator and determine the input and the output for loads up to 150 per cent. of the rated capacity.

(b) The losses.—If the alternator be driven by motor or other mechanical means, the losses which are known or which can be determined, the losses of the alternator may be measured. These losses are (1) windage and friction, (2) iron (core) loss, (3) field copper loss, (4) armature copper loss, (5) load losses.

Motor Losses.—Disconnect the motor and the alternator, run the motor at the proper speed and without load and determine the input to its armature. This input supplies the stray power of the motor which is constant (very nearly) and a small copper loss.

$$\text{Motor stray power}^{1} = EI - R_m I^2$$

(1) **Windage and Friction.**—Drive the alternator at rated speed but without field excitation.

$$\text{Windage and friction} = EI_1 - S_m - R_m I_1^2$$

(2) **Iron Losses.**—Excite alternator field to give rated voltage at rated speed.

$$\text{Iron losses} = EI_2 - S_m - R_m I_2^2 - W\&F_a$$

(3) **Field Copper Loss.**—From the saturation curve find the field current (I_3) required to give rated voltage on open circuit.

From the short-circuit curve find the current (I_4) required to give any desired current in the short-circuited armature winding.

Then the field current required to give rated voltage and the armature current at the same time is the vector sum of I_3 and I_4.

Determine the resistance (R_f) of the field winding.

$$\text{Field copper loss} = (I_3^2 + I_4^2)R_f$$

(*Note.*—The loss in the field rheostat should not be uded in the field loss as the rheostat is not a necessary : of the apparatus. See A.I.E.E. Rules.)

[1] ec Experiment 12 (Direct Currents) for method of keeping :ray power of the motor constant.

(4) **Armature Copper Loss.**—The copper loss of the armature winding is readily calculated for any value of armature current when the resistance of the winding is known.

(5) **Load Losses.**—The load losses include all losses not included in (1), (2), (3) and (4), are proportional to the load and are determined, for any given armature current, from the losses of the alternator when the armature winding is short-circuted and the field excitation is such that the given current flows in the short-circuited winding.

$$\text{Load losses} = EI_5 - S_m - R_m I_5^2 - W\&F_a - R_a I_a^2$$

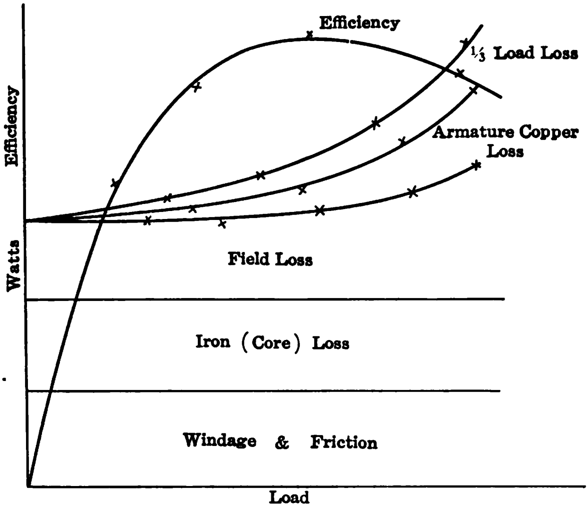


FIG. 39.

These losses are greater when the armature windin*g* is short-circuited than when operating under loa*d* conditions. Hence, the A.I.E.E. Rules recommen*d* that one-third the loss, as determined by the above method, be used in the efficiency calculations.

8. Determine the losses of an alternator, tabulate them and plot as in Fig. 39.

9. Calculate

(*a*) the efficiency for 25 per cent., 50 per cent., 75 per cent., 100 per cent., 125 per cent. and 150 per cent. of the rated capacity.

(*b*) the regulation for 100 per cent., 80 per cent. lagging and 80 per cent. leading power factor by

(1) the e.m.f. method.

(2) the m.m.f. method.

(*c*) the synchronous reactance of the alternator.

10. Plot the following curves:

(*a*) saturation.

(*b*) short-circuit.

(*c*) efficiency.

(*d*) voltage characteristic.

(1) for unity power factor.

(2) for 80 per cent. power factor leading.

(3) for 80 per cent. power factor lagging.

11. Explain

(*a*) why the e.m.f. method gives a poorer regulation than will probably be obtained by an actual load test.

(*b*) why the m.m.f. method gives a better regulation than may be expected on load test.

(*c*) why the voltage changes as the armature current changes.

(*d*) the meaning of the terms "synchronous impedence" and "synchronous reactance."

(*e*) why a considerable variation in the speed while taking data for the short-circuit curve is of little consequence.

(f) the effect of the power factor of the load circuit on the rating of an alternator.

(g) why the regulation of an alternator is poorer when the load is inductive than when it is non-inductive.

REFERENCES

Franklin & Esty, Alternating Currents, Chap. 7.
Karapetoff, Exp. Elec. Eng., Chap. 22.
Karapetoff, The Magnetic Circuit, Chap. 8.
Steinmetz, A.-C. Phenomena, Chap. 22.
Steinmetz, Elements, pp. 126–141.
Bedell, D.-C. & A.-C. Testing, Chap. 3.
Smith, Alternating Currents, Chap. 7.

3

PARALLEL OPERATION OF ALTERNATORS

The object of this experiment is to study the process of connecting two alternating-current generators so that they will supply a common load circuit, to determine the division of the load between them and the effect of unequal field excitation.

1. Connect two alternators as in Fig. 40. Regulate the speeds and the field excitations until the alternators have the same voltages and the lamps remain dark for several seconds at a time.

If all the lamps are not dark at the same instant interchange any two leads from the same machine.

One of the three switches may now be closed.

2. During a dark period of the lamps close the other two switches and note any momentary deflection of the ammeter pointer.

3. Open the switches, change the field excitation of

one machine by 10 per cent. to 25 per cent. and close the switches as before, noting the momentary and the permanent deflections of the ammeter.

Also read the voltmeters before and after closing the switches.

4. With the switches closed, change the field excitation of one machine and note the changes in the voltmeter and the ammeter indications.

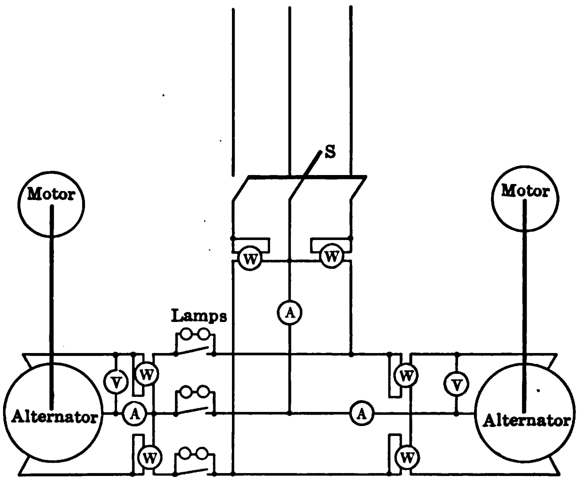


FIG. 40.

5. Load alternator A to approximately its rated capacity, synchronize and connect alternator B to the load circuit.

Regulate the driving torque of machine B until the lternators divide the load in proportion to their ratings. Increase the load to 125 per cent. of the combined ratings the machines and note the division of the load.

6. Reduce the excitation of one of the machines 10 er cent. to 25 per cent., increase that of the other so that

the voltage remains constant and note the load division, the total output being kept constant.

7. Reduce the driving torque of one machine until its wattmeters indicate approximately zero, disconnect the driving power and read all instruments. (The current leads of one set of wattmeters must be reversed, indicating that the relation of the current and the e.m.f. in this portion of the circuit has reversed or that this alternator is now running as a motor.)

8. Vary the field excitation of the motor and note the indications of the instruments, the voltage and the load being kept constant.

9. Increase the field excitation of the motor until one of the wattmeters indicates zero, reverse the current leads of this meter and increase the field excitation still further, keeping the voltage and the load as in (8).

(*Note.*—The load in (8) and (9) may be applied entirely or in part by loading the motor.)

10. Connect a synchroscope and use it in place of the lamps.

11. Explain

(*a*) why the wattmeter indications are practically constant in (6) although the ammeter indications vary greatly.

(*b*) why a momentary current flows between the machines if the switches are closed before the lamps become entirely dark.

(*c*) why a current flows between the machines if the field excitation of one machine is changed (switches closed).

(*d*) why the indications of both voltmeters change when the excitation of one machine is changed (switches closed).

(*e*) by means of a diagram, the conditions existing when the lamps are not all dark at the same ti (*f*) the synchroscope and state its advantages.

(*g*) why it is necessary to reverse the current leads of one wattmeter when the field excitation is increased beyond a certain value as in (9). What is the power factor of the motor circuit when one wattmeter indicates zero? How is the input to the motor found when measured by the two-wattmeter method? (Three-phase circuits.)

(*h*) why the wattmeters measuring the input to the motor (two wattmeters on three-phase circuit) do not read the same.

(*i*) by means of a diagram, the connections so that the lamps will not be dark at synchronism.

REFERENCES

Franklin & Esty, Alternating Currents, pp. 159–161.
Karapetoff, Exp. Elec. Eng., Chap. 25 & Vol. 1, pp. 357–363.
Steinmetz, A.-C. Phenomena, Chap. 23.
Steinmetz, Elements, pp. 154–161.
Bedell, D.-C. & A.-C. Testing, pp. 146–149.
Smith, Alternating Currents, pp. 235–242.
Standard Handbook.
Foster's Handbook.

4

THE SYNCHRONOUS MOTOR

The object of this experiment is to study the alternator when operated as a motor.

1. Starting.—The synchronous motor, as such, is not self starting though it may be made so (if polyphase) by converting it, temporarily, into an induction or hysteresis motor. This is done by opening the field circuit and supplying the armature with a reduced voltage by means of an auto-transformer or other starting device. Starting in this way, without load, the rotor will attain a speed close to synchronism (in some cases greater then synchronism) when the field switch may be closed and the motor will drop into "step" with the supply system and operate as a synchronous motor.

(*Warning.*—In starting a synchronous motor in the above manner, a dangerously high voltage is induced in the field windings. Great care should, therefore, be taken to avoid contact with the machine while starting.)

The synchronous motor may, also, be started by means of a small auxiliary motor (either D.-C. or A.-C.) attached to the shaft. When so started, it acts as a generator and must be synchronized (see Parallel Operation of Alternators) before the switch connecting it to the alternating-current system is closed. After connection is made to the alternating current system, the supply circuit of the starting motor is broken.

2. V-curves.—The synchronous motor exhibits the peculiarity that the line current may be changed by changing the excitation of the D.-C. field, the load remaining constant. A curve plotted with line current as ordinates and field current as abscissa has somewhat the shape of the letter V—hence the name, "V-curve." Starting with a small field current, the line current decreases to a minimum and then increases as the field excitation is increased. The point of minimum line current is the point of maximum power factor. For field excitations below this the current is lagging; above, leading. (See Fig. 41.)

3. Clock Diagram.—Draw (Fig. 42) OA proportional to the applied e.m.f. and let OB be the current vector making the angle AOB with the applied e.m.f. At right angles to OB erect OC proportional to the reactance drop, XI. Draw CD parallel to OB and proporti
the drop due to armature resistance, RI. The

line, *DA*, represents the motor or counter e.m.f., while the impedence drop, *ZI*, is represented by *OD*.

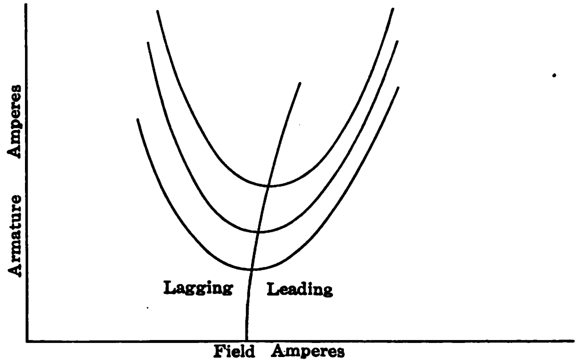


FIG. 41.

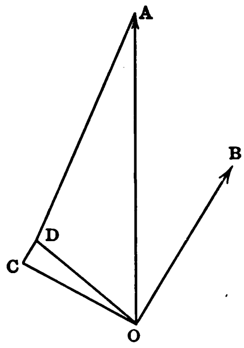


FIG. 42.

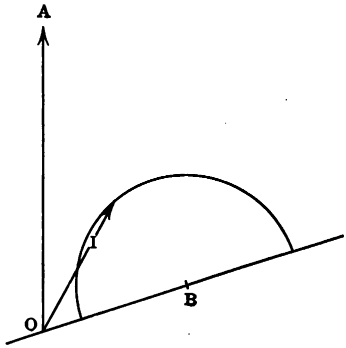


FIG. 43.

4. Circle Diagram.—If the vector, *OB* (Fig. 43) be rawn so that the cosine of the angle, *AOB*, equals the ›ower factor of the motor when the rotor is blocked and *ÒB* is made proportional to the applied e.m.f., the locus of the current vector is a semi-circle whose center is at B and whose radius is proportional to the field excitation, *i.e.*, to the counter e.m.f. Then for a given field excitation or counter e.m.f. the complete diagram for any load may be determined.

5. Efficiency.—The efficiency of a synchronous motor is determined (a) by a brake test, the input and the output being measured; (b) from the losses calculated as for an alternator.

6. Construct the following curves:

(*a*) efficiency.
(*b*) V-curves for not less than three different loads.
(*c*) vector (clock) diagram.
(*d*) circle diagram.

7. Explain

(*a*) how the power factor changes with the load, the field excitation remaining constant.
(*b*) how the shape of the V-curve affects the operation of the motor.
(*c*) why the field circuit is opened before starting as an induction motor.
(*d*) why the branches of the V-curve are not symmetrical.
(*e*) how the counter e.m.f. may be greater than the applied e.m.f.
(*f*) the effect of reversing the field current while the motor is in operation.
(*g*) the commercial applications of the synchronous motor.
(*h*) by means of a diagram, how the armature current (the load) increases, the speed remaini constant.
(*i*) "hunting," its cause and remedy.

REFERENCES

Franklin & Esty, Alternating Currents, Chap. 8.
Karapetoff, Exp. Elec. Eng., Chap. 21.
Steinmetz, A.-C. Phenomena, Chap. 24.
Steinmetz, Elements, pp. 141–154.
McAllister, A.-C. Motors, Chap. 10.
Bedell, D.-C. & A.-C. Testing, Chap. 2.
Smith, Alternating Currents, Chap. 8.
Standard Handbook.
Foster's Handbook.

5

THE ROTARY CONVERTER

The object of this experiment is to study the rotary or synchronous converter.

1. **Starting.**—When supplied with direct current the converter acts as a D.-C. motor and may be started as such by the use of the usual "starting box." Before connection is made to an alternating-current system, correct voltage and phase relations must be obtained. (See Parallel Operation of Alternators.)

When supplied with alternating current the converter is not self starting but may be started by induction (hysteresis) motor action as described for the synchronous motor. (See The Synchronous Motor.)

2. Run the converter as a D.-C. motor, measure the speed, the applied voltage and the voltage at the rings.

3. Change the field excitation and repeat (2).

4. Apply a load to the A.-C. side and repeat (2).

5. Change the field excitation and repeat (4).

6. Synchronize the A.-C. side with an A.-C. system of the proper voltage and frequency and note the effect of a change in field excitation on the speed of the rotary and on the current output, the load being kept constant.

7. Start as an induction (hysteresis) motor, noting the current intake before and after closing the field "break-up switch."

8. Run the converter as a synchronous motor, measure the speed, the applied voltage and the voltage at the D.-C. brushes.

9. Change the field excitation and repeat (8), also observing any change in the A.-C. ammeter indication.

10. Compounding.—The D.-C. voltage of a converter may be increased with the load by means of a series field winding provided there is inductance in the A.-C. supply circuit. The inherent inductance in the A.-C. system may be sufficient for this purpose or it may be introduced in the form of an auto-transformer, a reactance coil, or otherwise.

With the converter taking power from an A.-C. system and the D.-C. field provided with a compound winding, load the converter and note the change in voltage at the rings and at the D.-C. brushes, the voltage of the supply circuit being kept constant. (*Note.*—If no compound converter is available, the effect of an increased field excitation may be observed by increasing the shunt field current by means of the field rheostat.)

11. V-curves.—The converter has the same characteristic as a synchronous motor in that, with a given load, the A.-C. line current is a minimum for a certain field current. For field currents less than this, the line current increases in value and lags behind the e.m.f. For greater field excitations, the line current increases but leads the e.m.f.

12. Efficiency.—The efficiency of a converter is determined (*a*) by loading, (*b*) from the losses.

(*a*) Loading.—Load the converter and measure the input and the output.

(*b*) The losses.—The only measurements needed are the no-load input at rated speed and voltage, measured from either the A.-C. or the D.-C. side, and the resistance between the D.-C. brushes as determined by the voltmeter-ammeter or other D.-C. method.

Then

$$\text{per cent. efficiency} = \frac{(EI - RI^2)\,100}{EI + W}$$

when E = the rated D.-C. voltage.

I = the rated D.-C. current.

W = the no-load input in watts.

R = the effective armature resistance which is proportional to the resistance as measured between the D.-C. brushes and depends on the number of rings on the A.-C. side. To obtain the value of R multiply the measured resistance by the following:

For a 2-ring converter,	1.39
For a 3-ring converter,	0.56
For a 4-ring converter,	0.37
For a 6-ring converter,	0.26
For an 8-ring converter,	0.21

13. With current output as abscissa, plot the following curves:

(*a*) D.-C. voltage
(*b*) A.-C. voltage.
(*c*) watts input.
(*d*) watts output.
(*e*) losses.
(*f*) efficiency.

14. Explain

(*a*) the effect of a change in field excitation (1) when the converter is operated inverted and in parallel with synchronous generators; (2) when operated inverted but independent of synchronous machines; (3) when delivering direct current.

(*b*) the effect should the A.-C. system be disconnected from the converter when the converter is connected to a D.-C. system and operating with a weak field. What precaution should be taken to provide for such an emergency?

(*c*) the "split-pole" converter.

(*d*) the advantages and the disadvantages of the converter compared with other methods of conversion.

(*e*) the increase in the capacity of a given armature as the number of rings increases.

(*f*) how the presence of inductance in the A.-C. circuit makes compounding possible.

(*g*) why the effective resistance is different from the resistance as measured between the D.-C. brushes.

(*h*) why there is no need to shift the brushes as the load varies, as in the case of the D.-C. dynamo.

(*i*) why the theoretical and the observed ratios of A.-C. to D.-C. voltage are not the same.

REFERENCES

Franklin & Esty, Alternating Currents, Chap. 9.
Karapetoff, Exp. Elec. Eng., Chap. 23.
McAllister, A.-C. Motors, Chap. 10.
Smith, Alternating Currents, Chap. 10.
Steinmetz, Elements, pp. 217–160.
Standard Handbook.
Foster's Handbook.

6

THE INDUCTION MOTOR

The object of this experiment is to study the induction motor and to obtain data from which curves representing the actions of such a motor may be plotted.

1. Induction motors are divided into two classes differentiated, in construction, by the rotor winding.

(*a*) The squirrel-cage motor has a rotor whose conductors are insulated copper wires or bars placed in slots on a cylindrical, laminated iron core, the ends of the conductors being connected by copper rings, one on each end of the core.

(*b*) The wound rotor is one in which distinct windings are interconnected and the proper terminals brought out to slip rings mounted on the shaft. Through these slip rings connection is made to a rheostat by means of which the resistance of the rotor circuit may be varied.

2. Starting.—The induction motor is self starting (if polyphase) when supplied with alternating current of the proper frequency, voltage and number of phases. The squirrel-cage motor is usually started by supplying the stator with a voltage less than that at which the motor is rated, the line voltage being reduced by means of an auto-transformer or other step-down device. After the rotor attains a considerable speed, the line voltage is applied and the starting device automatically disconnected from the line.

In the wound-rotor type, rated voltage is supplied to the stator, resistance having been introduced into the rotor circuit. As the rotor speeds up, the resistance in the rotor circuit is reduced.

3. Performance Curves.—The performance of an induction motor is shown by curves as in Fig. 44, data for which may be derived from (*a*) a brake test, (*b*) the losses, (*c*) the circle diagram.

(*a*) Brake test.—Supply the motor from a circuit of the rated voltage and frequency, and determine the following quantities for loads up to 125 per cent. of the rated capacity:

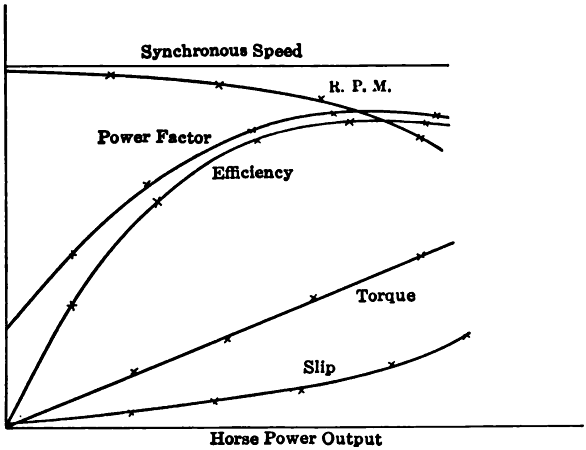


FIG. 44.

(1) watts input.
(2) voltage.
(3) current.
(4) torque.
(5) speed.
(6) slip.

(*b*) The losses.—The set-up for the determination of the losses is the same as that for the bra[illegible] test except that no torque measurements [illegible] be taken, the motor being connected to an electric generator or other apparatus by means of which it may be loaded.

At no-load the input is composed of the different motor losses—stray power (iron loss, windage and friction), stator copper loss and rotor copper loss. The stator copper loss is readily computed from the current input and the measured resistance of the stator windings. In the squirrel-cage rotor the copper losses in the rotor winding are small and may be neglected while in the wound rotor they are determined as readily as in the stator. Then

$$\text{Stray power} = \text{no-load input} - \text{copper losses}.$$

For any input

$$\text{Output} = \text{input} - \text{stray power} - \text{stator } I^2R - \text{rotor } I^2R.$$

But the rotor copper losses are porportional to the slip. Hence

$$\text{Output} = (\text{input} - \text{stray power} - \text{stator } I^2\text{R})\frac{100 - \text{per cent. slip}}{100}$$

The slip of an induction motor is easily measured, unless it becomes excessive, by the stroboscopic method. On the end of the shaft or pulley mark as many equally spaced radial lines as there are pairs of poles on the motor. Strongly illuminate these marks by means of an arc lamp supplied from the same source as the motor. When the motor is in operation, the radial lines appear to rotate in a direction opposite to that of the rotor. The speed of this apparent rotation is proportional to the slip of the rotor.

Another simple method for the determination of slip to connect a contact maker to the shaft of the motor that it will close, once in each revolution, the circuit a D.-C. voltmeter connected across the circuit supplying the motor. The voltmeter pointer will swing back and forth, the rate of swing being porportional to the slip of the rotor.

(*c*) The circle diagram.—By means of the circle diagram the performance of an induction motor is determined from two simple tests and the resistance of the stator winding.

No-load Test.—Run the motor without load, at its rated voltage and measure current and watts input.

Blocked Rotor Test.—Block the rotor to prevent its rotation, apply rated voltage and measure current and watts input.

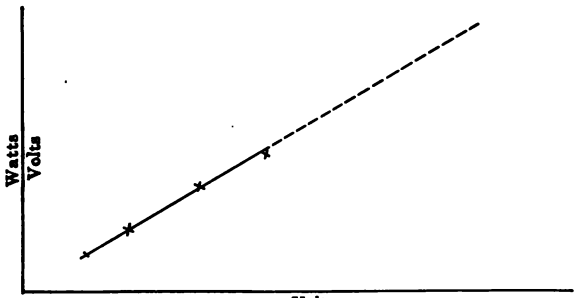


FIG. 45.

(*Note.*—It is often inadvisable to apply rated voltage to a motor with the rotor blocked because of the large currents that will flow in the windings. If several wattmeter readings be taken at voltages less than the rated voltage of the motor, a curve may be plotted between $\frac{\text{watts}}{\text{volts}}$ and volts (Fig. 45). This curve is a straight line and may be extended to any desired point, the ordinate of which, when multiplied by the abscissa, will give the watts input at that voltage. This makes it unnecessary to cause excessive currents to flow in th motor windings, but very low voltages should not be used, as the results, with such voltages, are likely to be erratic.

Construction of the Circle Diagram.—Draw *OA* (Fig. 46) proportional to the rated e.m.f. From *O* lay off *OB* proportional to the no-load current, the cosine of the angle, *AOB*, being equal to the power factor at no-load. From *B* draw the line, *BD*, parallel to the axis of abscissa. Also from *O* lay off the line, *OC*, proportional to the

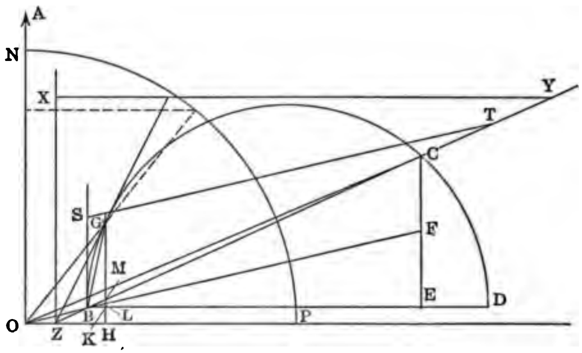


FIG. 46.

current with the rotor blocked, the cosine of the angle, *AOC*, being equal to the power factor under this condition. The points, *B* and *C*, are two points on the semicircular locus of the current vector, the center being on the line, *BD*.

The perpendicular to *BD* dropped from *C* is propor-ional to the copper loss with rotor blocked. From the ıeasured resistance of the stator winding and the mmeter reading the copper loss of the stator winding calculated and laid off proportional to *EF*. Draw traight lines from *C* and *F* to *B*. Then, for any stator current, as *OG*, the no-load losses (constant) are proportional to *HK*, the stator copper loss to *KL*, the rotor copper loss to *LM* and the motor output to *MG*. For any other value of current input, the relations may be found in a similar manner.

Power Factor.—With *O* as a center and any convenient radius, draw the arc, *NP*. The ratio of the projection of the current vector (produced if necessary) between *O* and the intersection with the quadrant on *OP* to *OP* is the power factor of the motor for that current input.

The maximum power factor at which an induction motor will operate is obtained when the current vector is tangent to the circle.

Slip.—Through the point, *T*, on *BC* (extended) draw a line parallel to *BF* and intersecting, at *S*, a perpendicular to the axis of abscissa erected at *B*. Divide the line, *ST*, into 100 equal parts, beginning at *S*. Draw a line from *B* through the end of the current vector to its intersection with *ST*. The slip is read directly from the scale on *ST*.

Efficiency.—Parallel to the axis of abscissa draw the line, *XY*, to its intersection with *BC* (extended). Also extend *BC* to its intersection with the axis of abscissa and erect the perpendicular, *XZ*. Divide *XY* into 100 equal parts, beginning at *Y*. Through *Z* and the end of the current vector draw a line, extending it to its intersection with *XY*. The efficiency is read directly from the scale, *XY*.

Maximum Output.—The maximum output of the motor is at that point where a line passing through the end of the current vector and tangent to the circle is parallel to *BC*.

4. Balancing.—When a polyphase motor is ope on a badly unbalanced system, there is a "balan effect which tends to equalize the system.

5. Cascade.—The speed of an induction motor may be reduced by increasing the resistance of the rotor circuit but this reduces the efficiency. If the rotor circuit be used to supply the stator circuit of a second motor instead of being dissipated in a rheostat, a reduction of speed is accomplished without greatly reducing the efficiency.

Connect the rotor windings of a wound rotor to the stator windings of another induction motor (wound or squirrel-cage) through an auto-transformer (if necessary, to get the proper voltage on the second machine) and note the speed and the load division when the shafts are tied together mechanically.

6. Frequency Changer.—When the rotor of an induction motor is driven at a speed less than synchronism, the motor acts both as a transformer and as a generator, the frequency of the rotor circuit depending on the speed of the rotor.

(*a*) Drive the rotor of a wound motor at various speeds from synchronism to synchronous speed backward and observe voltages and frequencies.

(*b*) Drive the rotor of a wound motor at such a speed as to obtain some desired frequency. Keep this frequency constant, load the rotor circuit by means of a water rheostat, motor or otherwise, and measure the following quantities:

(1) watts input to stator of motor.
(2) watts input to driving motor.
(3) watts output.

7. Single-phase Induction Motor.—The theory of the single-phase induction motor is rather complicated because of the irregular form of the current and flux waves. What has been said above is, however, applicable to the single-phase motor with only slight modifications.

(*a*) Using a single-phase motor (with an auxiliary starting phase) or a three-phase motor connected as in Fig. 47 determine
  (1) maximum line current.
  (2) current in running phase.
  (3) current in starting phase.
  (4) time required for motor to reach full speed.

(*b*) Determine the value of x and of r to give
  (1) minimum starting current.
  (2) minimum time to reach full speed.

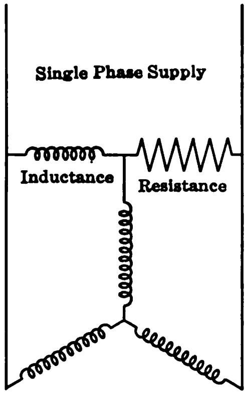


FIG. 47.

8. Determine, for an induction motor,

(*a*) the line disturbances caused in starting.
(*b*) the resistance of the stator winding.
(*c*) the "pull-out" torque in per cent. of full-load torque.
(*d*) the voltage required to give maximum starting torque.
(*e*) the slip by direct measurement.
(*f*) the stray power.

(*g*) the stator copper loss.
(*h*) the rotor copper loss.
(*i*) the maximum output.
(*k*) the maximum power factor.
(*l*) the efficiency at 25 per cent., 50 per cent., 75 per cent., 100 per cent., 125 per cent. and 150 per cent. of full-load.

9. Construct, for an induction motor,

(*a*) the circle diagram.
(*b*) the performance curves.
(1) speed.
(2) power factor.
(3) efficiency.
(4) torque.
(5) slip.

using horse-power output as abscissa.

10. Explain

(*a*) the relation between slip and losses. (Consider both single- and polyphase motors.)
(*b*) the relation between slip and load or torque.
(*c*) the effects when a polyphase motor is operated on an unbalanced system.
(*d*) the meaning of "synchronous watts" or "synchronous horse-power."
(*e*) the relation between slip and the frequency of the rotor circuit.
(*f*) the relation between slip and the voltage of the rotor circuit.
(*g*) the relation between slip and applied voltage, the load remaining constant.
(*h*) the relation between frequency and speed in a frequency changer.
(*i*) the relation between the frequency of the supply

system, that of the load circuit and the size of a frequency changer and its driving motor.

(*k*) the relation between the speed of the rotor and the e. m. f. of the rotor circuit in a frequency-changer set.

(*l*) the measurement of slip by the methods outlined in (3).

(*m*) the cause of the large starting current in the squirrel-cage motor.

REFERENCES

Franklin & Esty, Alternating Currents, Chap. 12–13.
Karapetoff, Exp. Elec. Eng., Chap. 24–25.
McAllister, A.-C. Motors.
Bailey, The Induction Motor.
Steinmetz, Elements, pp. 261–297, 315–320.
Smith, Alternating Currents, Chap. 11–12.
Foster's Handbook.
Standard Handbook.

7

THE INDUCTION GENERATOR

The object of this experiment is to study the action of the induction motor when run above synchronism.

1. Make connections as shown in Fig. 48. Regulate the speed and the field excitation of the alternator to give rated frequency and voltage. Close the switch, S_1, and start the induction motor in the usual way. Speed up the motor, *A*, so as to drive the induction motor above synchronism. Open the supply circuit of motor, *B*, and regulate the speed of the induction motor and the excitation of the synchronous machine so that the frequency and the voltage of the system are normal. Tabulate the readings of the instruments.

2. Close switch, S_2, and take readings for different out puts, keeping the speed and the field excitation constant

3. Repeat (2) keeping frequency and field excitation constant.

4. Repeat (2) keeping frequency and voltage constant.

5. With output as abscissa, plot curves with the following ordinates:

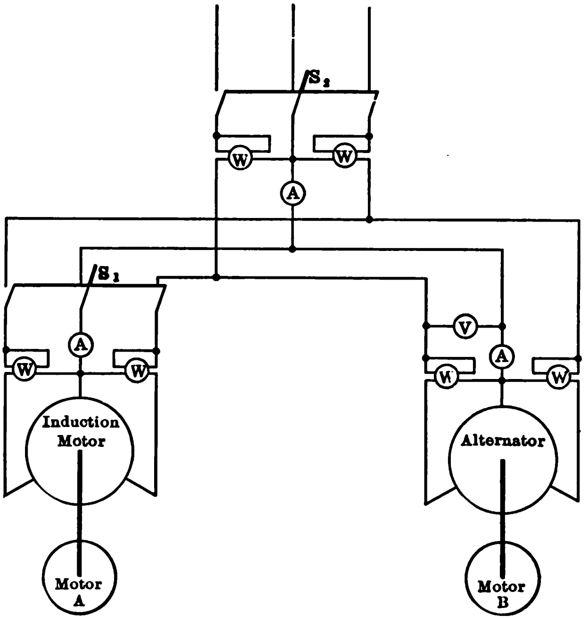


FIG. 48.

(*a*) frequency.
(*b*) voltage.
(*c*) speed.
(*d*) excitation.

6. Explain

(*a*) the relation between speed and frequency.
(*b*) the relation between voltage and excitation.

(*c*) the relation between speed and voltage.
(*d*) the relation between speed and load.
(*e*) the relation between voltage and load.
(*f*) the power-factor relations.
(*g*) why it is not necessary to synchronize the induction generator before connecting it to an A.-C. system.

REFERENCES

Franklin & Esty, Alternating Currents, p. 271.
McAllister, A.-C. Motors, Chap. 7.
Steinmetz, A.-C. Phenomena, pp. 310–319.
Steinmetz, Elements, pp. 291–307.
Bailey, The Induction Motor, Chap. 5.

8

THE SINGLE-PHASE COMMUTATING MOTOR

The object of this experiment is to study the single-phase commutating motor and to obtain data from which to plot the performance curves.

1. Connect the field and armature windings of a series A.-C. commutating motor to A.-C. mains of the rated voltage and frequency. Short-circuit the compensating winding. Determine the following:

(*a*) watts input.
(*b*) current.
(*c*) speed.
(*d*) torque.
(*e*) output.
(*f*) power factor.
(*g*) efficiency.

2. Repeat (1) with the compensating winding, the field winding and the armature winding in series.

3. Repeat (1) with the compensating winding open.

4. Repeat (1) with the armature winding disconnected from the supply circuit and the brushes short-circuited.

5. Repeat (4) with the compensating winding open.

6. Repeat (1), (2) and (3), using D.C. of such a voltage that the current does not become excessive.

7. Test other types of single-phase commutating motors.

8. Using horse-power output as abscissa, plot the following curves:

- (*a*) current.
- (*b*) power factor.
- (*c*) speed.
- (*d*) torque.
- (*e*) efficiency.
- (*f*) input.

9. Explain

- (*a*) the action of a D.-C. shunt motor when supplied with single-phase alternating current.
- (*b*) the action of a D.-C. shunt motor when the armature is supplied with current from one phase and the field with current from the other phase of a two-phase system.
- (*c*) the structural differences in the A.-C. and the D.-C. series motor.
- (*d*) the action of the compensating winding.
- (*e*) the action of the series motor when the brushes are short-circuited.
- (*f*) how excessive sparking in the A.-C. series motor is prevented.

10. Compare the starting torques for the same armature current when the same motor is operated on A.C. and on D.C.

REFERENCES

Franklin & Estey, Alternating Currents, Chap. 14.
McAllister, A.-C. Motors, Chap. 12–15.
Steinmetz, A.-C. Phenomena, Chap. 27.
Bailey, The Induction Motor, Chap. 14.
Smith, Alternating Currents, Chap. 12.
Standard Handbook.
Foster's Handbook.

9

THE CONSTANT POTENTIAL TRANSFORMER

The object of this experiment is to study the constant potential transformer and to determine the losses, the regulation, the efficiency and the heating.

1. The Losses.—The losses in a transformer are (*a*) iron losses, (*b*) copper losses.

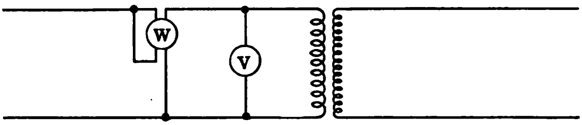


FIG. 49.

(*a*) Iron losses.—Connect the transformer as in Fig. 49 and impress on it voltages varying from 20 per cent. to 150 per cent. of the rated e.m.f., the frequency being kept constant. The wattmeter will indicate the iron loss plus a small copper loss. Since the copper loss is that due to the small no-load current, it may usually be neglected.

Tabulate not less than six readings of watts and volts.

(*b*) Copper losses.—Connect the transformer as in Fig. 50 and impress on one of the windings (preferably the high-tension) such voltages as will cause the current to vary from zero to 150 per cent. of full-load (rated) value. The wattmeter will indicate the copper loss plus a small iron loss which is neglected.

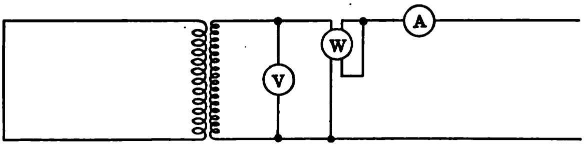


FIG. 50.

Tabulate the wattmeter, voltmeter and ammeter readings for not less than six values of current.

(*Note.*—This will require only a small percentage of the normal voltage and care should be taken that too large a voltage is not applied or an excessive current may flow and the transformer or the instruments be damaged.)

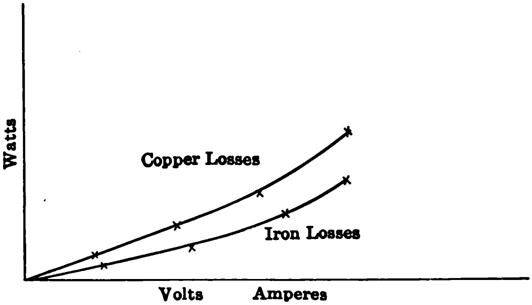


FIG. 51.

2. Efficiency.—The efficiency of a transformer is determined (*a*) by loading, (*b*) from the losses as found in (1) above, (*c*) by an opposition test.

(*a*) Loading.—Supply the transformer with current at the rated e.m.f. and measure the input and the output for loads from zero to 150 per cent. of the rated load.

(*b*) From the losses.—From the iron-loss curve (Fig. 51) the core loss for the rated e.m.f. may be obtained. This loss is practically constant for varying values of current so long as the applied voltage is constant.

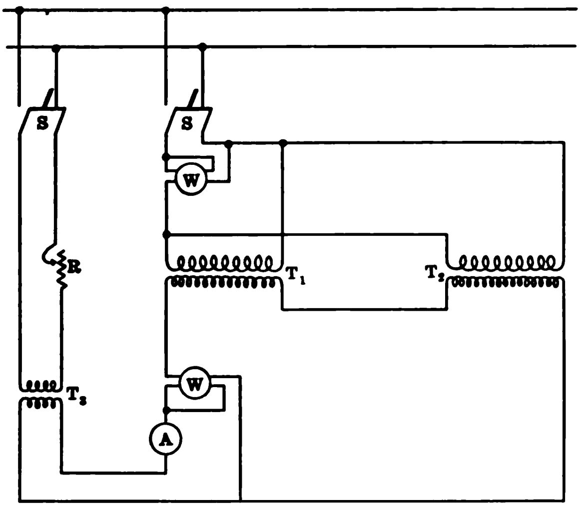


FIG. 52.

The copper loss varies as the square of the current and its value for any load current may be obtained directly from the copper-loss curve (Fig. 51).

(*c*) Opposition test.—Connect two identical transformers as in Fig. 52 (protecting them by suitable fuses or circuit breakers) to a circuit of the rated voltage and frequency.

Regulate the e.m.f. applied to the transformer, T_3, an take wattmeter readings for current values varying fro zero to 150 per cent. of rated current as indicated by the ammeter. The wattmeters will indicate the losses of the two transformers under load conditions.

(*Note.*—Disconnect the voltmeter leads and the connections to the potential coils of the wattmeters before opening or closing the supply circuits.)

3. Regulation.—The regulation of a transformer is calculated from (*a*) loading, (*b*) the losses.

(*a*) Loading.—Determine the secondary voltage at no-load and at full-load, keeping the primary e.m.f. constant at its rated value.

(*b*) From the losses.—From the data obtained in (*lb*) or (2*c*)

$$W = RI^2$$

$$R = \frac{W}{I^2}$$

$$Z = \frac{E}{I}$$

$$X = \sqrt{Z^2 - R^2}$$

when R = the equivalent resistance of both coils.

Z = the equivalent impedence of both coils.

X = the equivalent reactance of both coils.

W = the copper loss in the transformer.

then $E_0 = \sqrt{(E_1 \cos \phi + RI)^2 + (E_1 \sin \phi + XI)^2}$.

when E_0 = the no-load voltage.

E_1 = the rated voltage.

$\cos \phi$ = the power factor of the load circuit.

4. Kapp's Diagram.—The regulation of a transformer is determined graphically by means of Kapp's diagram (Fig. 53).

With O as a center and a radius proportional to the rated primary e.m.f., describe a semicircle. On the diameter, DE, lay off OA proportional to XI, the reactance drop at full-load. At right angles to DE erect the current vector, I, and lay off AB proportional to the full-load resistance drop, RI. From B draw the vector, BC, to the intersection with the semicircle and making the angle, ϕ, whose cosine is the power factor of the load

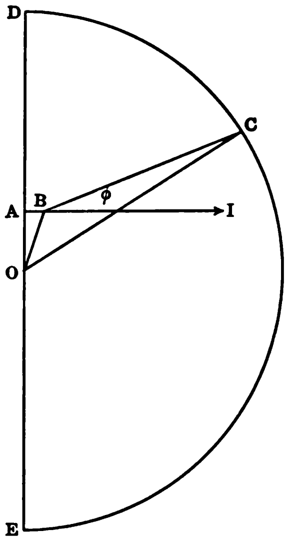


FIG. 53.

circuit, with the current vector. BC is proportional to the secondary voltage reduced to the primary circuit.

5. Heat Test.—The rise in temperature due to the losses limits the output of a given transformer. This rise in temperature is determined (*a*) by loading, (*b*) from an opposition test.

(*a*) Loading.—After determining the resistance of the windings, operate the transformer at rated voltage and full-load current. Take periodi readings of thermometers placed in the oil of the transformer and measure, at regular intervals, the resistances of the windings.

(*b*) Opposition test.—Connect two identical transformers as in Fig. 52.

Supply the transformer, T_3, with such a voltage that the ammeter indicates that full-load current is flowing in the coils of the transformer under test. Take periodic readings of the thermometers placed in the oil of the transformer and of the wattmeters connected in the supply circuits.

6. Ultimate Temperature.—It is often inconvenient to prolong a heat test until the maximum temperature is

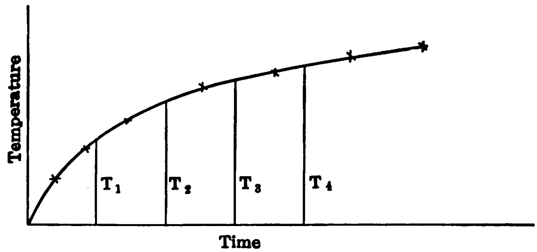


FIG. 54.

reached. This temperature may be calculated in the following manner: On the heating curve (Fig. 54) mark off four equal abscissa whose ordinates are T_1, T_2, T_3, T_4. The ultimate temperature

$$= \frac{T_1}{1-\left[\frac{T_4-T_3}{T_2-T_1}\right]^{\frac{1}{2}}}$$

$$= \frac{T_2}{1-\left[\frac{T_4-T_3}{T_2-T_1}\right]}$$

$$= \frac{T_3}{1 - \left[\dfrac{T_4 - T_3}{T_2 - T_1}\right]^{\frac{3}{2}}}$$

$$= \frac{T_4}{1 - \left[\dfrac{T_4 - T_3}{T_2 - T_1}\right]^2}$$

(*Note.*—All four calculations should be made and the average value taken as the value to which the temperature of the transformer will ultimately rise.)

7. Separation of the Iron Losses.—The iron losses of a transformer may be separated into hysteresis and eddy-current losses as in Section 4 of the experiment on Iron Losses.

8. Obtain data for and construct

- (*a*) iron-loss curve.
- (*b*) copper-loss curve.
- (*c*) efficiency curve.
- (*d*) Kapp's diagram for
  - (1) 100 per cent. power factor.
  - (2) 80 per cent. power factor leading.
  - (3) 80 per cent. power factor lagging.
- (*e*) temperature curve from
  - (1) thermometer readings.
  - (2) resistance.

9. Determine

- (*a*) per cent. regulation for
  - (1) 100 per cent. power factor.
  - (2) 80 per cent. cent. power factor leading.
  - (3) 80 per cent. power factor lagging.
- (*b*) the equivalent resistance.
- (*c*) the equivalent reactance.
- (*d*) the ultimate temperature.

10. Explain

(*a*) the advantages of the opposition test.
(*b*) the action of the transformer, T_3, in the opposition test.
(*c*) why the temperature as calculated from resistance measurements differs from that indicated by thermometers.
(*d*) "all-day efficiency."
(*e*) equivalent resistance and reactance.
(*f*) why the determination of regulation by loading is usually unsatisfactory.
(*g*) why transformers should be rated in KVA instead of in KW.
(*h*) the relation of the losses at maximum efficiency.
(*i*) the disadvantages of an efficiency test by loading.
(*k*) why the iron losses change as the temperature of the transformer increases.
(*l*) the effect of the power factor of the load circuit on the regulation of a transformer.

11. Show

(*a*) that the copper losses are negligible in the measurements for the determination of iron losses and that the iron losses are negligible in the measurements for the determination of copper losses.
(*b*) that a resistance in the primary circuit and one in the secondary circuit are equivalent when their ratio is the square of the ratio of the number of turns in the windings.

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Bedell, D.-C. & A.-C. Testing, Chap. 5.

Fleming, The Transformer.
Smith, Alternating Currents, Chap. 6.
Steinmetz, Elements, pp. 60–79.
Foster's Handbook.
Standard Handbook.

10

THE AUTO-TRANSFORMER

The object of this experiment is to study the single-coil or auto-transformer.

1. Connect an auto-transformer as in Fig. 55, and read watts, volts and amperes for various loads.

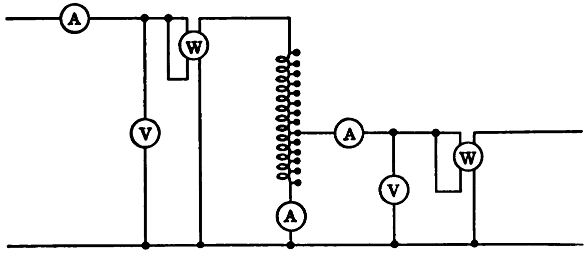

FIG. 55.

2. Calculate
   (*a*) efficiency.
   (*b*) regulation.
3. Explain
   (*a*) the current relations as indicated by the three ammeters.
   (*b*) the voltage relations.
   (*c*) why it is not advisable to use auto-transformer for lighting or power service.
   (*d*) the use of an ordinary 10 : 1 transformer as a auto-transformer.

4. Compare
   (*a*) the copper losses in the two parts of the winding of an auto-transformer.
   (*b*) the total copper loss of an auto-transformer with that of an ordinary transformer having the same primary and secondary e.m.f., the same primary and secondary resistances and the same output.

5. Give the chief commercial uses of the auto-transformer.

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Franklin & Esty, Alternating Currents, pp. 219–221.
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Bedell, D.-C. & A.-C. Testing, Chap. 5.
Smith, Alternating Currents, Chap. 6.
Standard Handbook.
Foster's Handbook.

11

TRANSFORMER CONNECTIONS

The object of this experiment is to study the various transformer connections, both single-phase and polyphase

1. Single-phase.—A variety of connections (giving different secondary voltages) for the single-phase transformer are available when the primary and the secondary windings are divided into two coils, as is the case in most commercial transformers. The following connec- ... in more general use:

Both primary and secondary coils in series. Fig. 56.

Both primary and secondary coils in parallel. Fig. 57.

(*c*) Primary coils in series, secondary coils in parallel. Fig. 58.

(*d*) Primary coils in parallel, secondary coils in series. Fig. 59.

In (*a*) and (*d*) a three-wire distributing system is obtained by the addition of a connection at the junction of the secondary coils, as indicated by the dotted lines.

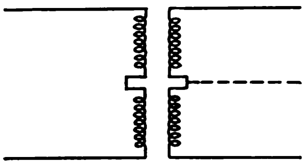

FIG. 56.

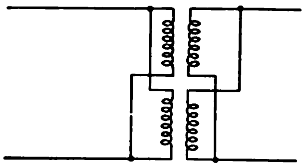

FIG. 57.

(*Warning.*—It is possible to connect the coils of a transformer so that they form a local short-circuit. Hence, it is always advisable in making any connections, to protect the transformers by circuit breakers or fuses of proper capacity in the primary circuit.)

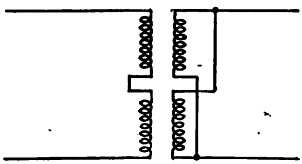

FIG. 58.

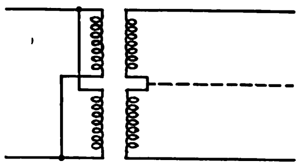

FIG. 59.

2. Polyphase.—Two-phase currents are transformed by connecting a single transformer to each phase, all the connections given under (1) being available. I addition, interconnection of the primaries or of secondaries, or of both, may be made.

Three-phase transformer connections are the follow (*a*) Delta-delta.—In this connection three transformers are used, the three coils (primary or secondary) forming the sides of a triangle, the line connections being made at the corners of the triangle or the junction of two transformer windings. Fig. 60.

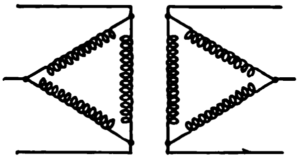

FIG. 60.

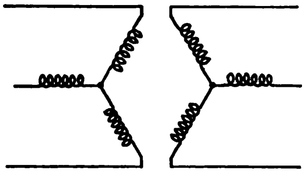

FIG. 61.

(*b*) Star-star.—In this connection three terminals (primary or secondary) are tied together, the other three terminals being connected to the line. Fig. 61.

(*c*) Delta-star.—This connection is a combination of (*a*) and (*b*), the primaries being connected delta and the secondaries star. Fig. 62.

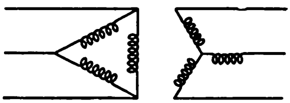

FIG. 62.

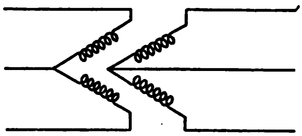

FIG. 63.

(*d*) Star-delta.—This connection is the same as (*c*) except that the primaries are star and the secondaries delta.

(*Warning*.—The same precautions should be taken to protect the transformers when making polyphase connections as for single-phase, and tests made to see that the triangle of voltages is symmetrical.)

3. V- or Open-delta.—It is possible to operate a three-phase system with only two transformers although the current relations are somewhat distorted. The connections are shown in Fig. 63.

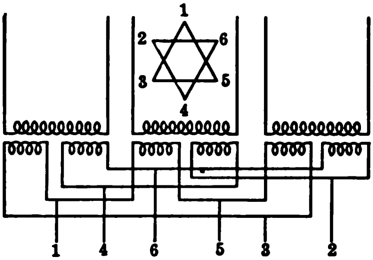

FIG. 64.

4. For the operation of large rotary converters, it is desirable to use six phases. Three-phase to six-phase transformation may be accomplished in any of the follow-

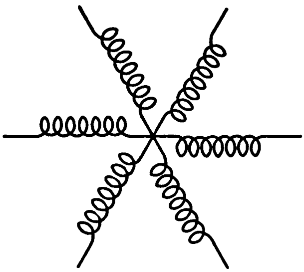

FIG. 65.

ing ways, the primaries being connected either star or delta to three-phase mains:

(*a*) Double-delta.—This connection requires use of transformers, the secondary wind of which are divided. By means of the c nections indicated in Fig. 64, two deltas are formed which, when taken together, form a six-phase system.

(*b*) Double-star.—In this connection one terminal

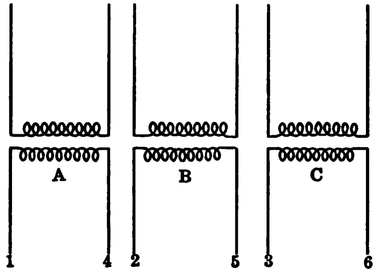

FIG. 66.

of each of the six secondary coils is connected to a common point, the remaining terminals forming the line connections. Fig. 65.

(*c*) Diametral.—In this connection the terminals

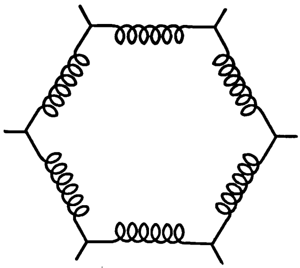

FIG. 67.

of transformer *A* are connected to rings (1) and (4) of the rotary, those of *B* to rings (2) and (5) and those of *C* to rings (3) and (6). Fig. 66.

(*d*) Hexagonal.—The six secondary coils are joined so as to form a hexagon, a line connection being made at the junction of two coils. Fig. 67.

5. The Scott Transformation.—Two-phase to three-phase or three-phase to two-phase transformation is accomplished by means of two transformers connected as in Fig. 68. The three-phase coils are connected in "*T*," *i.e.*, the terminal of one coil is connected to the middle point of the other coil. The two-phase coils are independent of each other. To get the proper

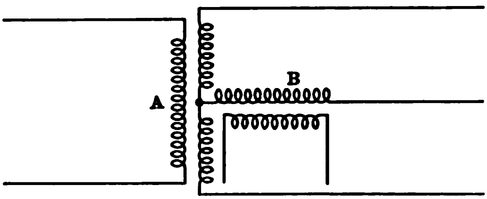

FIG. 68.

voltage relations it is necessary that the number of turns in the three-phase coil of transformer *B* equal 0.866 times the number of turns in the three-phase coil of transformer *A*.

6. Find the voltage relations when single 10 : 1 transformers are connected

(*a*) as in Fig. 56.
(*b*) as in Fig. 57.
(*c*) as in Fig. 58.
(*d*) as in Fig. 59.
(*e*) as in Fig. 60.
(*f*) as in Fig. 61.
(*g*) as in Fig. 62.
(*h*) as in Fig. 63.

(*i*) as in Fig. 64.
(*k*) as in Fig. 65.
(*l*) as in Fig. 66.
(*m*) as in Fig. 67.

7. Find the two-phase voltage when two 10 : 1 transformers are used to transform 2,200-volt three-phase to two-phase by Scott's method.

8. Explain

(*a*) why the measured voltage from line to neutral in a three-phase star-delta connection may not be equal to the line to line voltage divided by the square root of three.
(*b*) by means of a clock diagram, the three-phase current and voltage relations in a Scott transformation.
(*c*) by means of a clock diagram, the current and voltage relations in the V-or open-delta connection.
(*d*) the advantages of and the objections to the V-connection.
(*e*) the advantages of star connection and state where these advantages become highly important.
(*f*) the advantage of delta connection for secondary distributing systems.
(*g*) the use of the star-delta system.

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inmetz, A.-C. Phenomena, Chap. 36.
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12

IRON LOSSES

The object of this experiment is to determine the losses in iron, to separate such losses into their components (hysteresis and eddy current) and to determine the value of Steinmetz's exponent and of Steinmetz's coefficient.

1. Apparatus.—The apparatus used in this experiment is that of Eppstein, and consists of four coils of insulated

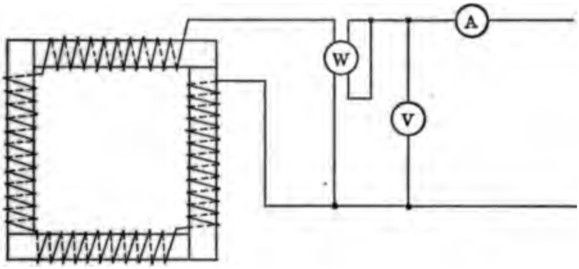

FIG. 69.

wire connected in series and arranged to form the sides of a square as in Fig. 69. The cores of the coils are built up of strips of the iron to be tested, the strips being of uniform dimensions and arranged as shown (with "butt" joints at the corners).

It is desirable to have the dimensions of the apparatus and of the core such that a simple change of the decimal point will give the loss per unit of weight and that the value of β (maximum flux density for a sine wave of e.m.f.) may be readily computed from the voltage and the frequency of the supply circuit.

One of these results is obtained by making the total weight of the core 10 kilograms (slightly greater than 2 pounds), the other by making the area of the core and the number of turns in the coils such that

$$\frac{10^8}{4.44NA}=k$$

when k = a constant the value of which is some multiple of 100.

N = the number of series turns on the coils.

A = the cross sectional area of the iron.

Then

$$\beta=k\frac{E}{f}$$

when E = the effective value of the e.m.f. induced in the coil but which may be taken, in a properly constructed apparatus, as equal to the e.m.f. impressed on the terminals of the coils.

f = frequency of the supply circuit.

2. Connect the apparatus as shown in Fig. 69 and take readings over as wide a range of voltage as possible, the frequency being varied so that $\frac{E}{f}$ is a constant, thus keeping the flux density constant.

3. Repeat (2) for several different values of flux density.

4. The wattmeter will indicate the iron loss plus a small copper loss. In a properly constructed apparatus the latter loss is negligible.

Then

$$W=W_h+W_e=k_hf+k_ef^2$$

when $$k_h=aV\beta^{1.6}$$

and $$k_e=bVl^2\beta^2.$$

By dividing the above expression by f we obtain

$$\frac{W}{f}=k_h+k_ef$$

which is the equation of a straight line between $\frac{W}{f}$ and f. Plot this curve (*ab* Fig. 70) and extend it to the intersection with the axis of ordinates. The value of the ordinate, *oc*, is that of the constant, k_h.

By multiplying the ordinate, $oc = k_h$, by any frequency, the watts lost in hysteresis is determined for that frequency and the flux density (constant) for which the measurements were taken.

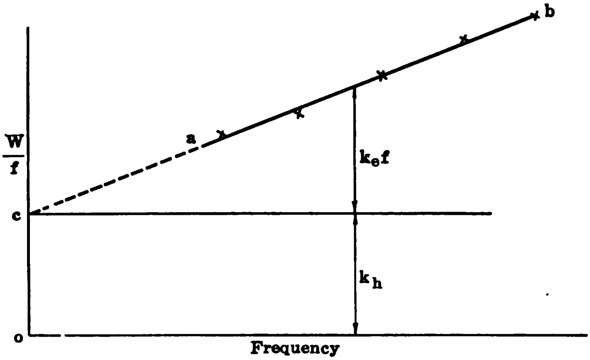

FIG. 70.

Likewise the eddy-current loss is obtained for this flux density and any given frequency by multiplying the ordinate, $k_e f$, for that frequency by the frequency.

The hysteresis and eddy-current losses determined above may be plotted as in Fig. 71.

5. Steinmetz's Exponent.—The equation for hysteresis loss

$$W_h = aVf\beta^x$$

may be written

$$W_h = k_h{}^1 E^x$$

since a, f and V are constants, and β is proportional to E. The latter expression may, in turn, be written

$$\log W = \log k_h{}^1 + x \log E.$$

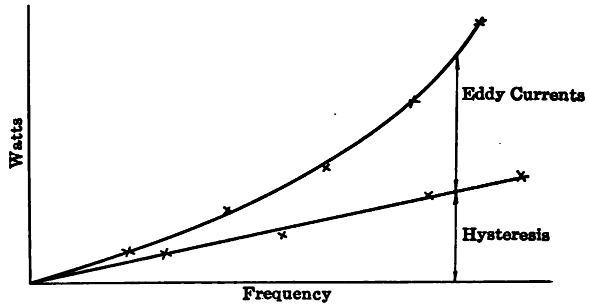

FIG. 71.

This equation is that of a straight line between log W and log E, the tangent of the angle between the line and the axis of abscissa being the required value of x.

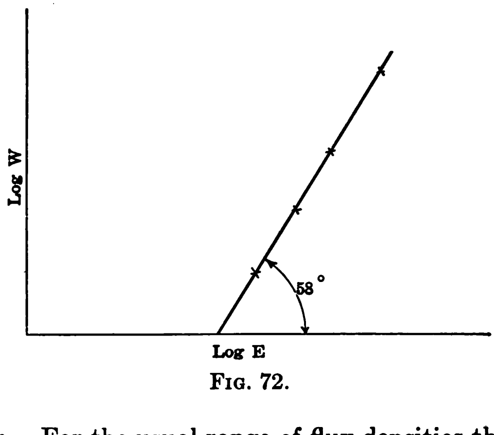

FIG. 72.

(*Note.*—For the usual range of flux densities this angle should approximate 58° for which the value of $x = 1.6$, which is the value commonly assigned for Steinmetz's exponent.)

Find, by means outlined above, the hysteresis loss for several values of E (over as wide a range as possible) but for the same frequency, so that the flux density will change, plot the log equation as in Fig. 72 and determine the value of x.

6. Steinmetz's Coefficient.—If the hysteresis loss in iron is expressed in ergs per cubic centimeter per cycle, we have

$$P = N\beta^{1.6}$$

N being Steinmetz's coefficient which expresses the magnetic quality of the iron. From the hysteresis loss determined above, the dimensions of the core and the constant of the apparatus $(\beta = k\frac{E}{f})$ the quality of the iron is determined.

7. Determine

(*a*) hysteresis and eddy-current losses and plot them as in Fig. 71.
(*b*) the value of Steinmetz's exponent.
(*c*) the electrical quality of the iron.

8. Explain

(*a*) the effect of a change of frequency on the iron losses.
(*b*) how varying the voltage and the frequency in the same ratio keeps the flux density constant.
(*c*) the effect on the iron losses of laminating the iron.

9. If the iron tested were used in the core of a 2,200:220 volt transformer, determine the iron losses at 60 cycl as compared to those at 25 cycles.

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Franklin & Esty, Alternating Currents, pp. 211–212.
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Karapetoff, Exp. Elec. Eng., Chap. 10.
Karapetoff, The Magnetic Circuit, Chap. 3.
Smith, Alternating Currents, pp. 160–163, 229–233.
Standard Handbook.
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13

THE CONSTANT CURRENT TRANSFORMER

The object of this experiment is to study the transformer used to supply constant current to a series arc-lighting system from constant potential mains.

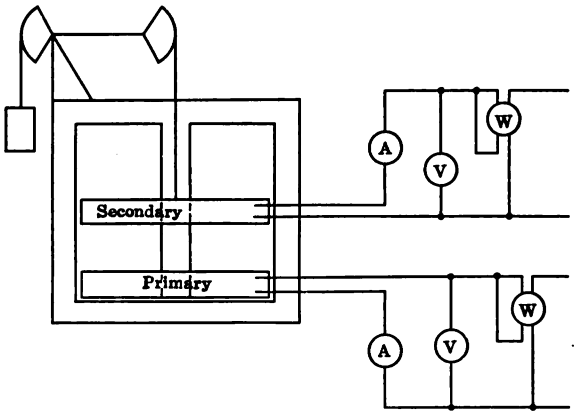

FIG. 73.

1. Connect as in Fig. 73 and record the indications of he instruments for an increasing number of lamps.
2. Repeat (1) for a non-inductive load, such as a water rheostat.
3. Determine the resistance of the primary and of the

secondary winding, from which the copper losses for any current value may be calculated.

Then

Iron losses = watts input − watts output − copper losses.

4. Plot curves using KW output as abscissa and the following as ordinates:

(*a*) primary e.m.f.
(*b*) primary current.
(*c*) primary power factor.
(*d*) secondary e.m.f.
(*e*) secondary current.
(*f*) secondary power factor.
(*g*) total copper losses.
(*h*) iron losses.
(*i*) efficiency.

5. Explain

(*a*) how the primary current and e.m.f. remain practically constant with varying load.
(*b*) why the iron losses change as the load varies.
(*c*) the relation between the losses at maximum efficiency.
(*d*) the cause of the low power factor of the arc-lamp circuit.
(*e*) why the distance between the two coils varies as the load changes.
(*f*) how the ratio of voltage transformation changes, the ratio of the number of turns in the coils being constant.

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Franklin & Esty, Alternating Currents, pp. 215–217.
Karapetoff, Exp. Elec. Eng., Vol. 1, pp. 240–243.
Crocker, Electric Lighting, pp. 171–174.
Foster's Handbook.
Standard Handbook.

14

THE MERCURY-ARC RECTIFIER

The object of this experiment is the study of the mercury arc as used for the rectification of alternating currents.

1. The mercury-arc rectifier consists of a vacuum tube containing a small quantity of mercury, which forms an

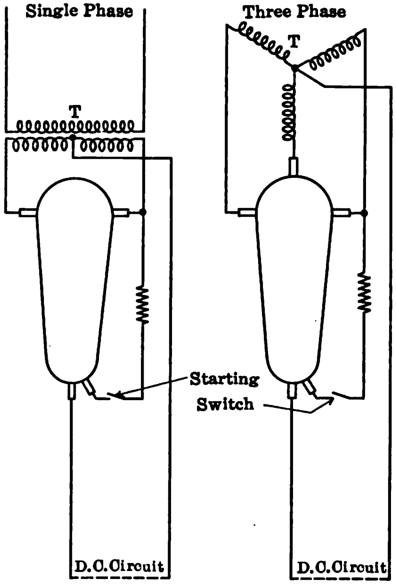

FIG. 74.

e to which one terminal of the D.-C. circuit is ,ed, two or more iron or graphite terminals, to the A.-C. lines are connected and an auxiliary ıry electrode for starting. It may be operated on ɔr single-phase or polyphase circuits. Diagrams single- and for three-phase circuits are shown in Fig.

74. The direct current is constant potential or constant amperage, depending on whether *T* is a constant potential or a constant current transformer.

2. Starting.—Close the D.-C. circuit (through a resistance such that the current will not become excessive), close the starting switch and shake or tilt the bulb until the two mercury electrodes are connected by the liquid. Open the starting switch and let the bulb return to its normal position.

3. Measure the following for constant A.-C. voltage:

(*a*) A.-C. voltage.
(*b*) A.-C. amperes.
(*c*) D.-C. voltage.
(*d*) D.-C. amperes.
(*e*) watts input.
(*f*) watts output.

4. Repeat (3) for constant current in the D.-C. circuit.

5. Calculate the following for (3) and (4):

(*a*) efficiency.
(*b*) power factor of the A.-C. circuit.

6. With watts output as abscissa, plot the following curves from data obtained in (3) and (4):

(*a*) A.-C. voltage.
(*b*) A.-C. amperes.
(*c*) D.-C. voltage.
(*d*) D.-C. amperes.
(*e*) efficiency.
(*f*) power factor of the A.-C. circuit.

7. Explain

(*a*) the need of the auxiliary electrode and starting circuit.
(*b*) the use and effect of an inductance in D.-C. circuit.

(*c*) why the apparatus will not operate with the D.-C. circuit open.
(*d*) why the efficiency increases with increased A.-C. voltage.
(*e*) why A.-C. instruments should be used in the D.-C. circuit.
(*f*) the conditions affecting the life of the tube and how the life is prolonged.
(*g*) why the mercury-arc rectifier is not used to supply D.-C. motors.
(*h*) why the arc "breaks" when the D.-C. amperes fall below a certain minimum value.
(*i*) the effect should mercury be deposited on the alternating-current terminals.
(*k*) the relation of the D.-C. voltage to the A.-C. voltage.

REFERENCES

Franklin & Esty, Alternating Currents, pp. 171–172.
Standard Handbook.
Foster's Handbook.
Current publications.

15

INSULATION (BREAKDOWN) TEST

The object of this experiment is to familiarize the student with the conduct of a high-voltage insulation test and to determine the relative insulating values of different materials.

1. Connect a high-voltage transformer as in Fig. 75. Supply the primary (low voltage) of the transformer from a circuit the voltage of which may be varied between wide limits.

(*Warning.*—Extreme care must be taken during the performance of this experiment that no part of the apparatus is touched except when the switch of the primary circuit is open, as the voltage is likely to be very high.)

2. Flat Insulation.—Materials like Fuller board, cloth and mica may be tested by placing a suitable

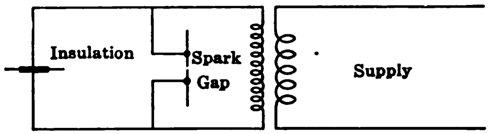

FIG. 75.

piece of the material between terminals connected to the high-voltage winding, as shown in Fig. 76, and gradually increasing the applied voltage until breakdown occurs.

Separate the terminals and determine, by means of the

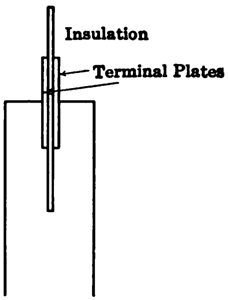

FIG. 76.

spark gap, the "sparking" distance, in air, for the same primary (applied) voltage. The breakdown voltage may be determined by reference to Fig. 77.

(*Note.*—Do not use burned or blunt needles in de mining the sparking distance.)

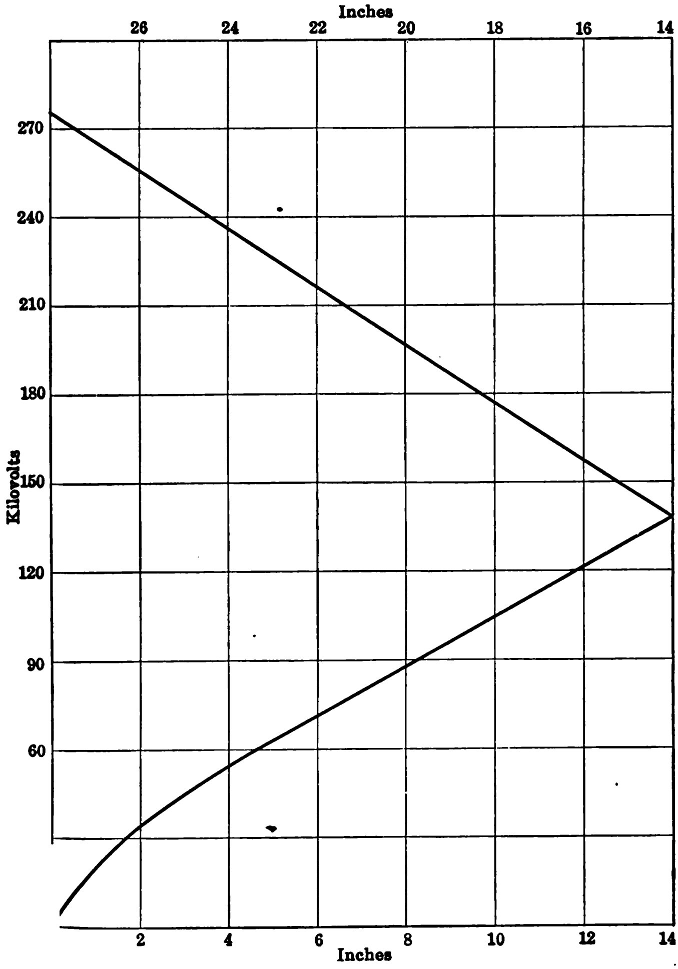
Inches
26
24
22
20
18
16
14
270
240
210
180
Kilovolts
150
120
90
60
2
4
6
8
10
12
14
Inches

FIG. 77.

3. Wire Insulation.—Immerse the wire, the insulation of which is to be tested, in a vessel of salt water, connect one terminal of the transformer to the salt water, the other to the wire and proceed as in (2).

4. Porcelain, Glass and Other Shaped Insulation.—Connect to the high-voltage winding by means of salt-water terminals and proceed as in (2).

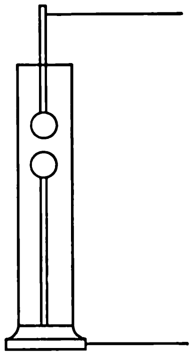

FIG. 78.

Darken the room and note

(*a*) the discharge over the surface of a high-voltage pole-line insulator.

(*b*) the corona at high voltages.

5. Oil.—When oil is to be tested it is placed in a glass vessel having two polished spherical terminals (Fig. 78) which are connected to the high-voltage winding of the testing transformer. The upper terminal is movable by means of a micrometer screw or other device, so that the distance between the balls may be easily changed and measured.

6. Compare the insulating properties of

(*a*) different materials of the same thickness.

(*b*) different thicknesses of the same material.
(*c*) two or more layers of a given material with a single layer of the same total depth.

7. Determine the breakdown voltage of
 (*a*) wire or cable insulation.
 (*b*) transformer oil.

REFERENCES

Karapetoff, Exp. Elec. Eng., Vol. 2, pp. 82–88.
Standard Handbook.
Foster's Handbook.

16

WAVE FORM

The object of this experiment is to study the form of e.m.f. and current waves and to determine the effects of different types of load on the wave form.

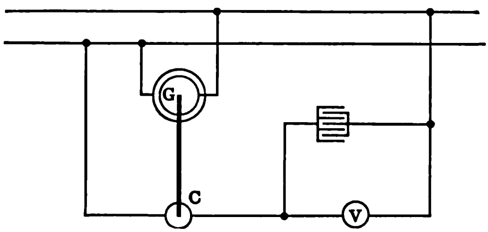

FIG. 79.

nethods are available for determinin g the
e.m.f. or current wave, (*a*) the point-to -point
the oscillograph.

contact maker.—A simple and easily
lied point-to-point method consists o f the
nections shown in Fig. 79, where *G* i s the
nerator, the wave form of which is to be

determined, or a small synchronous motor supplied with current from such a source. C is a contact maker driven by the generator (or the motor) and so arranged that an instantaneous current is sent through the circuit once in each revolution.

(*b*) The oscillograph.—In the oscillograph, rotating or vibrating mirrors are caused to reflect a beam of light onto a screen or a photographic plate. Two motions, at right angles to each other, are

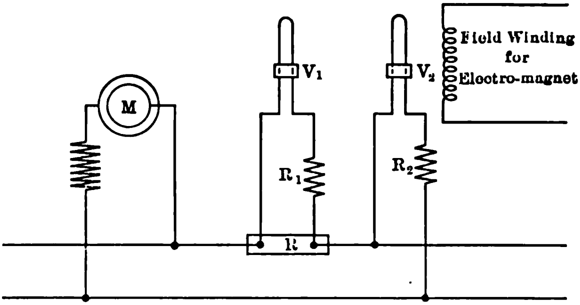

FIG. 80.

required to give a correct representation of wave form, one proportional to the magnitude of the current or e.m.f., the other constant. Fig. 80 represents the electrical circuits of an oscillograph provided with two vibrators so that the current and e.m.f. waves may be taken simultaneously.

M is a small synchronous motor which vibrates or rotates a mirror, the period of vibration of which is constant; v_1 and v_2 are the vibrators the deflections of which are proportional to the instantaneous value of the current or the e.m.f. R is a current shunt in series the load while R_1 and R_2 are resistances in the vibrator circuits.

3. Determine the current and the e.m.f. wave from for
   (*a*) non-inductive load,
   (*b*) over-excited synchronous motor.
   (*c*) under-excited synchronous motor.
   (*d*) synchronous motor load at unity power factor.
   (*e*) induction motor load.
   (*f*) an unloaded transformer.
   (*g*) the primary of a constant current transformer.
   (*h*) the secondary of a constant current transformer (1) on an arc circuit, (2) on non-inductive circuit.
   (*h*) the secondary of a constant current transformer (1) on an arc circuit, (2) on non-inductive circuit.
   (*i*) the mercury arc rectifier (A.-C. side).
   (*k*) the mercury arc rectifier (D.-C. side).
   (*l*) current in neutral between generator and a threec-phase motor; e.m.f. line to neutral.
   (*m*) current in neutral between star-connected transformers; e.m.f. line to neutral.
   (*n*) current in line; e.m.f. between lines of a three-phase, non-inductive system.
   (*o*) open-delta transformer connection.
   (*p*) three-phase and two-phase sides of a Scott transformation. (Test the current and the voltage relations in each line and the junction of the coils on the three-phase side.)
4 Explain
   he use of the condenser in the contact method.
   hy the waves differ in shape for different ads.
   ıe current and voltage relations found in (3*p*).
   .ow the power factor of a circuit may be determined from an oscillogram.

(*e*) the cause of the triple frequency currents in the neutral of a star-connected system.

REFERENCES

Karapetoff, Exp. Elec. Eng., Chap. 27.
Kinzbrunner, Alternating Currents, Chap. 8.

APPENDIX

Power Measurements and Wattmeter Connections

This article is written for reference in making connections for the measurement of power in the above experiments rather than as an additional experiment. It is the writer's belief that all the experimental work desirable in power measurement can be best given in connection with other experiments where the measurement of power is required, by the use of different wattmeter connections for different experiments.

1. General Method.—The general method, which requires one less wattmeter than there are conductors in the system, is applicable to any system of any number of phases and under any condition of balanced or unbalanced loading. Any conductor may be regarded as a common return for all the others. The current coil of a wattmeter is connected in each conductor (except the one selected as the common return) and the potential coil is connected from the conductor to the common return. The algebraic sum of the wattmeter readings is the power of the system. The connections for single-phase (Fig. 81) and for three-phase (Fig. 82) illustrate this method.

In using the general method for three-phase systems, '' readings are equal only when the load is balanced and ›wer factor is unity. Thus in Fig. 82 the readings : unequal for any load, balanced or unbalanced, power factor is less than unity and, if the power is less than 50 per cent., one of the meter readings ;ative, *i.e.*, the numerical difference of the readings : power in the circuit.

To determine if the power factor of a three-phase load circuit is greater or less than 50 per cent., measure the power in a non-inductive circuit, connecting the coils so that the meters indicate properly. With the same meter connections measure the power in the circuit whose power factor is unknown and if the terminals of the

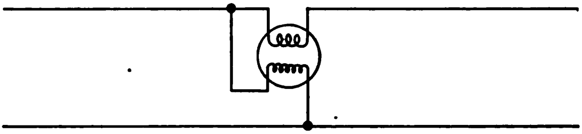

FIG. 81.

current coil of one wattmeter must be reserved to make it indicate properly, the reading of that meter should be regarded as negative and the power factor of the circuit is less than 50 per cent.

Another simple method of determining whether the power factor of the load circuit is greater or less than 50

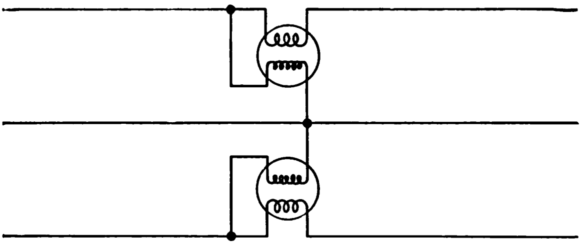

FIG. 82.

per cent. is to interchange the two meters without altering the relative connections of the current and potential coils. If the deflections are in the same direction as before the meters were interchanged, the power factor is greater than 50 per cent.

From the two wattmeter readings the angle betwee the current and the e.m.f. vectors may be determined, for balanced load and sine waves, from the following equation:

$$\phi = \tan^{-1} \frac{W_1 - W_2}{W_1 + W_2} \sqrt{3}$$

By providing suitable switches so that one meter may be alternately connected to different phases, only one meter is required for the measurement of power by the two-wattmeter method.

2. Single Meter Methods on Three-phase Systems.—When the potential coil of the wattmeter can be connected to the neutral of a three-phase system, the con-

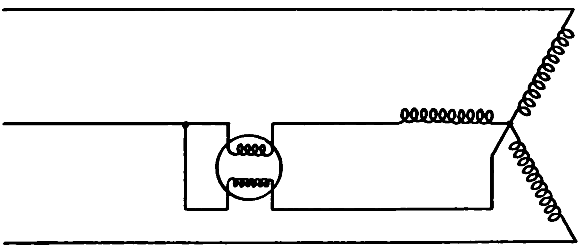

FIG. 83.

nections shown in Fig. 83 may be used. If the load is balanced, three times the wattmeter indication is the total power of the system or the meter may be calibrated to read total power direct. If the load is not balanced, switches must be provided for connecting the current successively in each of the circuits, and the sum of indications taken as the power of the system.

nless the ratio of the resistance of the potential iit of the wattmeter to R_1, R_2 and R_3 is high, an reciable error is introduced due to the shunting of rent around the load resistance. This error is ninated by the use of a "*Y*" multiplier in which two

resistances, each equal to that of the potential circuit of the wattmeter, are connected with the wattmeter coil to form an "artificial *Y*." Fig 84.

3. Polyphase Wattmeters.—The polyphase wattmeter is a combination of two or more single elements acting on the same moving part. Each pair of coils

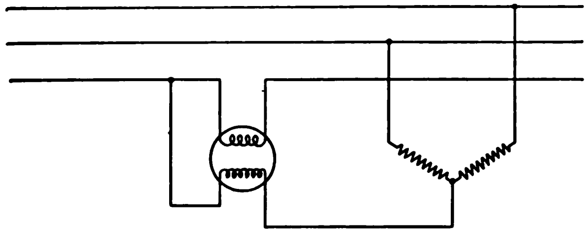

FIG. 84.

(voltage and current) is connected as in a single-phase meter and tested to give a deflection in the proper direction, considering the power factor of the load circuit as explained in Section 1.

REFERENCES

Kinzbrunner, Alternating Currents, Chap. 6.
Bedell, D.-C. & A.-C. Testing, Chap. 6.
Karapetoff, Exp. Elec. Eng., Chap. 25.
Smith, Alternating Currents, pp. 278–285.
Foster's Handbook.
Standard Handbook.

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